



ARSET


Applied Remote Sensing Training

<http://arset.gsfc.nasa.gov>

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SilvaCarbon

<http://egsc.usgs.gov/silvacarbon/index.html>

 @SilvaCarbon

Remote sensing of forest cover and change assessment for carbon monitoring

Instructors: Cindy Schmidt and Amber McCullum

Week 2: June 16, 2016

Course Structure

- One lecture per week – every Thursday from June 9 to July 7 at 1:00-2:30pm and 10:00-11:30pm EDT(-04:00 UTC)
- Please only sign up for and attend the same session each week
 - Lectures
 - Q&A
 - Homework exercises
- Webinar recordings, PowerPoint presentations, in-class exercises, and homework assignments can be found after each session at:
 - <http://arset.gsfc.nasa.gov/ecoforecasting/webinars/carbon-monitoring-2016>
 - Q&A: Following each lecture and/or by email (cynthia.l.schmidt@nasa.gov) or (amberjean.mccullum@nasa.gov)

Homework and Certificates

- Homework
 - Answers must be submitted via Google Form
- Certificate of Completion:
 - Attend all 5 webinars
 - Complete all 5 homework assignments by the deadline (access from ARSET website above)
 - **Week 2 HW Deadline: June 30th**
 - You will receive certificates approximately 2 months after the completion of the course from:
marines.martins@ssaihq.com

Carbon Monitoring Homework 1

Please complete all of these questions and submit the form to receive credit. Homework must be submitted by June 23rd, 2016.

Name *
Your answer

Email *
Your answer

1. Which of these data portals do NOT provide Landsat data? *

☐ A. GloVis
☐ B. Earth Explorer
☐ C. MRTWeb
☐ D. WELD

2. What is the color of the forest in the image?

☐ A. Red - High Carbon
☐ B. Near Infrared
☐ C. Green - Low Carbon
☐ D. Red - High Carbon

3. Chlorophyll is a measure of the amount of green vegetation in an area.

ARSET
Applied Remote Sensing Training
<http://arset.gsfc.nasa.gov>

Land Management
presents
a Certificate of Completion
to
Amber McCullum
for completing the advanced training:
"Remote sensing of forest cover and change assessment for carbon monitoring"
June 9 - July 7, 2016

Cindy Schmidt; Amber Jean McCullum

July 7, 2016

Prerequisite



- Fundamentals of Remote Sensing
 - Sessions 1 and 2A (Land)
 - On-demand webinar available anytime
 - <http://arset.gsfc.nasa.gov/webinars/fundamentals-remote-sensing>

On-Demand Training on Fundamentals of Remote Sensing

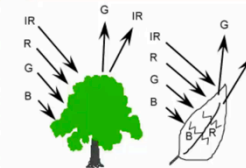
These on-demand sessions are intended to provide a basic overview of remote sensing. They are recommended as prerequisites for future courses in land management, wildfires, and water resources.

Session 1 is a general overview applicable to all the application areas mentioned above. There are two different Session 2 recordings specific to A) land management and wildfires and B) water resources. This training can be freely accessed at any time with a short user registration. Users can also download pdf versions of the presentations using the links below. No certificates will be provided for this training.

We hope you enjoy this on-demand training opportunity!

Presentation	Recording
 Session1: Fundamentals of Remote Sensing	External Link to Session 1 Recording
 Session 2A: Satellites, Sensors, Data, and Tools for Land Mgmt and Wild	External Link to Session 2A Land
Session 2B: Sat Resource Applic	

Interaction with Earth Surface: Vegetation



Example: Healthy, green vegetation **absorbs Blue and Red** wavelengths and **reflects Green and Infrared**



Since we cannot see infrared radiation, we see healthy vegetation as green

Accessing Course Materials

<https://arset.gsfc.nasa.gov/land/webinars/carbon-monitoring-2016>

ARSET
Applied Remote Sensing Training

Home About Trainings

Remote Sensing of Forest Cover and Change Assessment for Carbon Monitoring

Dates: Thursday, June 9, 2016 to Thursday, July 7, 2016
Times: 1:00-2:30 p.m. and 10:00-11:30 p.m. EDT (UTC-4)
Registration Closes: Monday, June 6, 2016

In this introductory webinar, participants will be provided with an overview of carbon monitoring for terrestrial ecosystems. This will include background information about the Intergovernmental Panel on Climate Change (IPCC), Greenhouse Gas (GHG) inventories, the United Nations Framework Convention on Climate Change (UNFCCC), and development of the Reducing Emissions from Deforestation and Degradation (REDD+) program. This course will review products from Landsat, MODIS, and Sentinel, and other sensors commonly used for land management applications.

This course will provide information about carbon estimation techniques, and conducting accuracy assessments on these estimates. This course will also provide live demonstrations of tools for carbon monitoring such as NASA's Carbon Mapper. Finally, guidance on reporting and verification of carbon estimates and the larger role of carbon markets will be discussed as well as additional guidance resources available to participants. There will be homework for participants to complete each week; this is required for a certificate of completion.

Land Management

Land Webinars -

Upcoming Training

Disasters

Using NASA Remote Sensing for Disaster Management
06/09/2016 to 06/30/2016

Airquality

Fundamentals of Satellite Remote Sensing for Health Monitoring
06/02/2016 to 06/30/2016

Land

Remote Sensing of Forest Cover and Change Assessment for Carbon Monitoring
06/09/2016 to 07/07/2016

Course Agenda:

[Detailed Agenda.pdf](#)

Session One: Overview of Carbon Monitoring for Terrestrial Ecosystems

June 9, 2016

An overview of policy on carbon monitoring, importance of forest monitoring (IPCC Greenhouse Gas Inventories and REDD+), performing a key category analysis, and elements of National Forest Monitoring Systems (NEMS).

- Presentation Slides (English)
- Homework Assignment

Session Two: Sensors and Products Available for Terrestrial Ecosystems

June 16, 2016

An overview of available satellite sensors and products available to monitor terrestrial ecosystems, pre-processing imagery requirements, image classification and change detection, considerations for NEMS sustainability, and a demonstration of NASA's Carbon Mapper.

- Presentation Slides (English)
- Homework Assignment

Session Three: Carbon Estimation Techniques and Methods

Designing a field campaign to collect carbon pool information, ground data collection and use in estimating carbon pools, the use of remote sensing in supporting the National Forest Inventory, and how to derive carbon emissions.

- Presentation Slides (English)
- Homework Assignment

Session Four: Accuracy Assessment

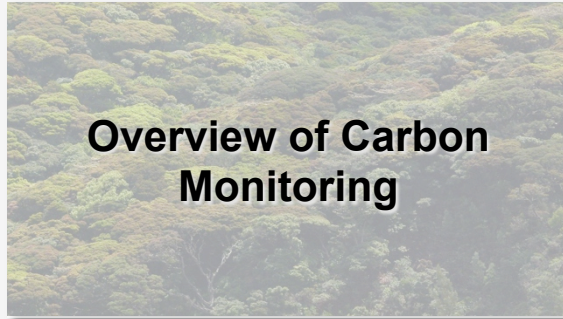
Developing an accuracy assessment, calculating accuracy statistics, and a demonstration of the Boston Education in Earth Observation Data Analysis (BEEODA) tools.

- Presentation Slides (English)
- Homework Assignment

Course materials are provided here using each specified link and will be active after each week

Course Outline

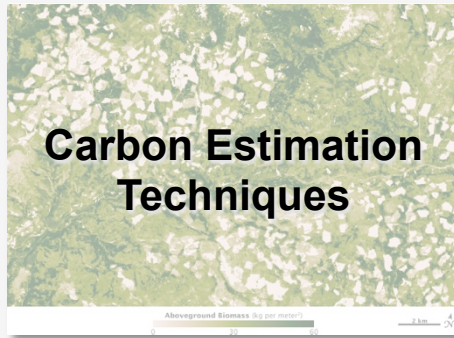
Week 1



Week 2

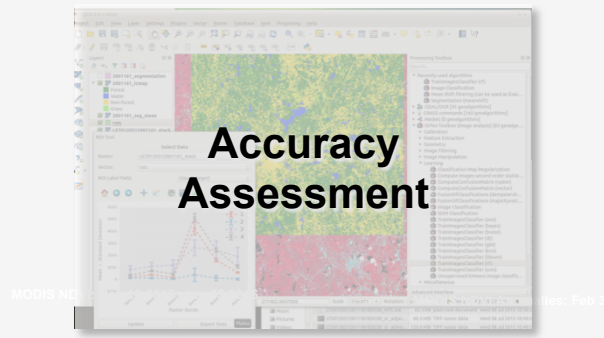


Week 3



National Aeronautics and Space Administration

Week 4



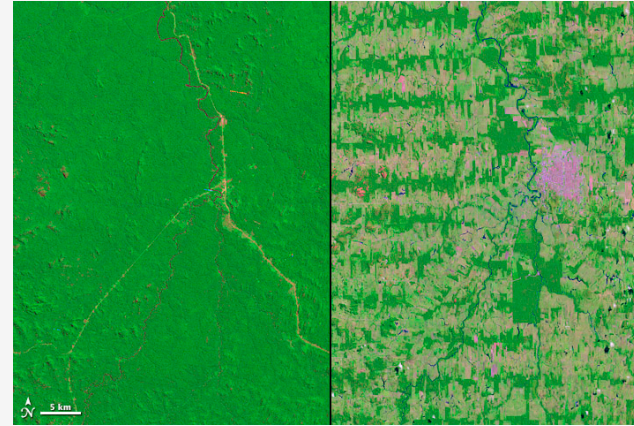
Week 5



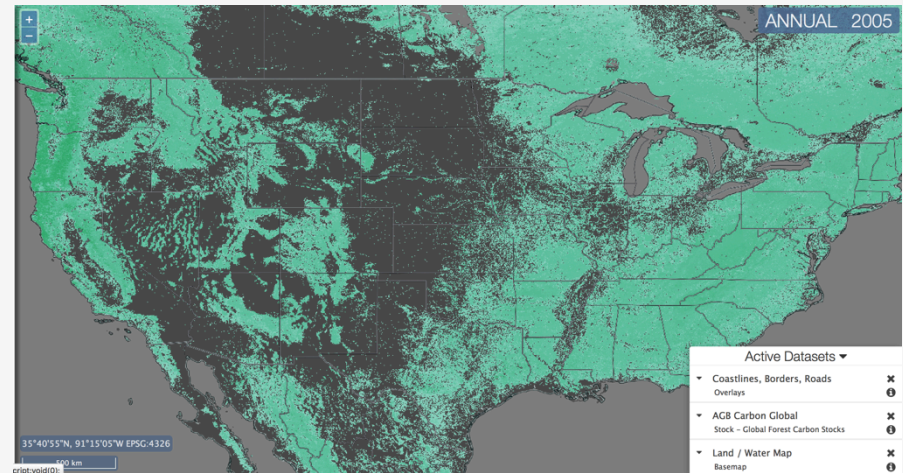
Applied Remote Sensing Training Program

Week 2 Agenda

- About ARSET
- What is Activity Data?
- Remote sensing data sources
- Pre-processing image requirements
- Image classification and change detection
- Considerations for National Forest Monitoring Systems (NFMS) sustainability
- NASA's Carbon Mapper
- Q&A



(Left)
Deforestation in
Brazil as shown by
Landsat images
from 1975 and
2012. Credit: Earth
Observatory.
(Below) NASA's
Carbon Mapper



The background of the slide is an aerial photograph of a coastline. On the left, the deep blue ocean meets a white sandy beach. To the right of the beach is a lush green landscape with a network of roads and fields. A large, semi-transparent circular area is overlaid on the right side of the image, containing a grayscale topographic map of a mountain range with a prominent peak. The text 'About ARSET' is positioned on the left side of this circular inset, with a horizontal line extending from its right edge.

About ARSET

Applied Remote Sensing Training Program (ARSET)

<http://arset.gsfc.nasa.gov>

Training activities for environmental professionals to increase usage of NASA observational and modeling data for decision-making support.



Online Webinars

- 1 hr a week, 4-6 weeks
- Live & recorded
- Include demos on data access



In-person Workshops

- Held in a computer lab for 2 - 4 days
- Focus on data access
- Locally relevant case studies



Train the Trainers

- Courses & training manuals for those interested in doing their own remote sensing trainings

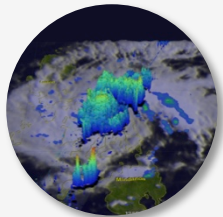
Applied Remote Sensing Training Program (ARSET)

<http://arset.gsfc.nasa.gov>

Provide online and on-site trainings tailored to:

- policy makers
- regulatory agencies
- applied environmental professionals

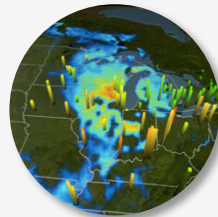
to increase the use of NASA Earth Science models & data for environmental applications:



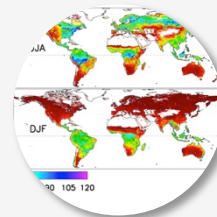
Disasters



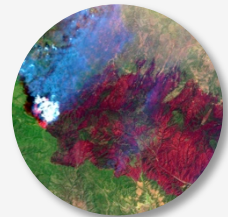
Ecoforecasting



Health &
Air Quality



Water Resources



Wildfires

ARSET Trainings

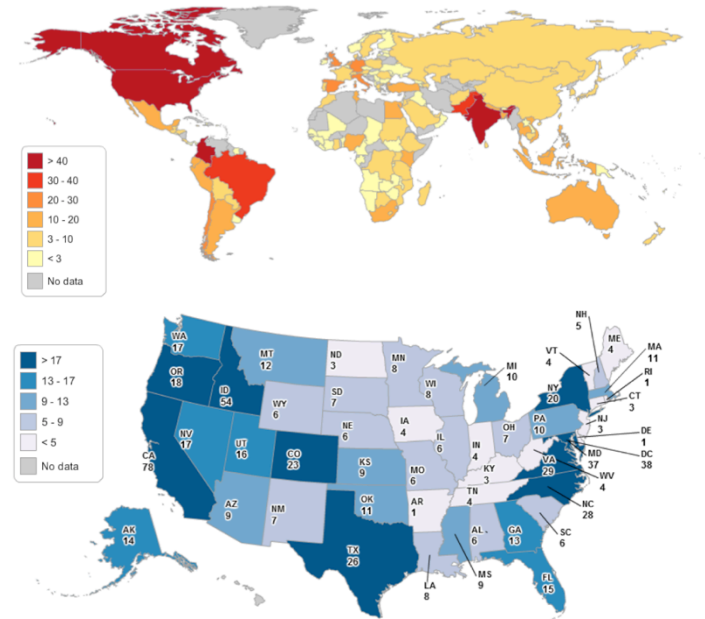
Impact & Accomplishments

- 68 Trainings Completed
- 4,900+ participants worldwide from:
 - 1,600+ organizations
 - 130+ countries
- More participants trained in 2015 than all previous years combined

“The greatest benefit [of this training] is knowing where to find and access remote sensing data concerning vegetation cover and basic tools for analyzing habitat trends and characterizing rate of change.”

– U.S. Federal Government Employee,
2016 Advanced NDVI webinar

Number of Participating Organizations by Country & U.S. States (2008-2015)



An aerial photograph of a coastline with a semi-transparent circular overlay. The overlay features a grayscale image of a mountain peak with a bright, starburst-like light at its summit. The text 'What is Activity Data?' is centered within the overlay, with a horizontal line extending from its left side.

What is Activity Data?

What is Activity Data?

- IPCC guidelines refer to two basic inputs for calculating greenhouse gas inventories: **activity data** and **emission factors**
- Encourage spatially explicit land conversion information, derived from sampling or wall-to-wall mapping techniques
 - Examples of Activity Data include areas transferred from forest to other land uses
- Estimates are generally derived from maps produced using remote sensing
 - Especially good for tropical countries where accessibility to forested areas may be limited

Activity Data

Key role for Earth observations in monitoring forests

- Fundamental requirement of national monitoring systems are that they:
 - Measure changes throughout all forested area
 - Use consistent methodologies at repeated intervals to obtain accurate results
 - Verify results with ground-based or very high resolution observations
- Remote sensing data supported by ground-based observations is the only practical solution to implement for inaccessible forest areas

Activity Data

Requirements for REDD+ Activities

- Areas of different forest types
- Annual conversion from forest to non-forest land uses
- Annual transfer from one forest type to another
- Annual conversion from non-forest land uses to planted or other forest

Example of (A) conversion from forest to non-forest: Small subsistence plots in Central Africa replace once-forested hillsides; (B) conversion of one forest type to another: Palm oil plantations in Indonesia replace primary forests

A



B

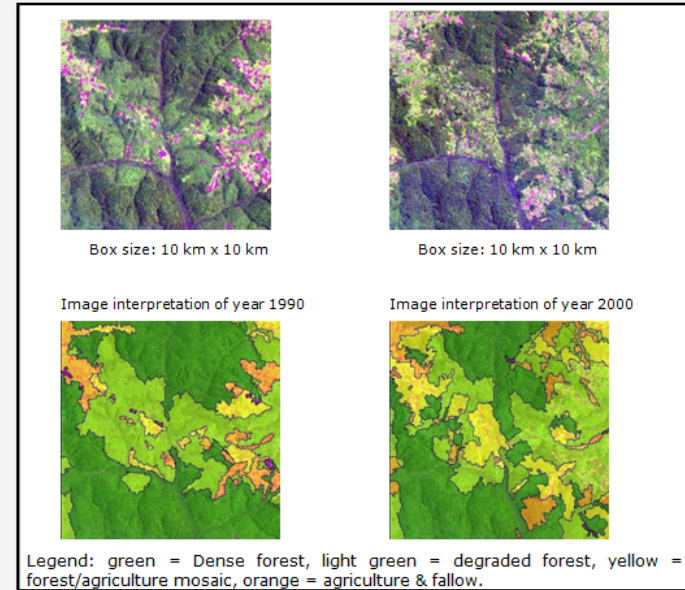


Source: earthobservatory.nasa.gov

Activity Data

Recommended remote sensing map products

- Forest/non-forest map (+ change maps)
- Forest Stratification
- Comprehensive land use maps (+ change)
- Change within forest land



Landcover maps derived from Landsat for an area in the Congo Basin. Source: GOF-C-GOLD Sourcebook 2014

An aerial photograph of a mountain range. A large, semi-transparent, light-colored circular area is centered over a prominent snow-capped mountain peak. The surrounding landscape is green and hilly. The ocean is visible on the left side of the image.

Remote Sensing Data Sources

Remote Sensing Data Sources

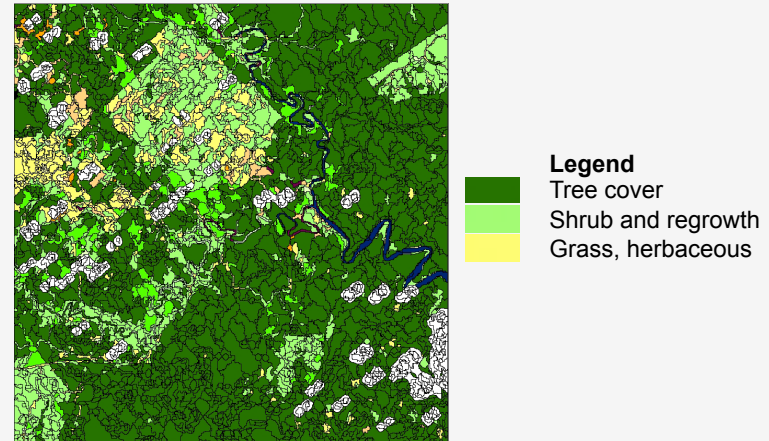
Overview

- Coarse spatial resolution (optical)
- Medium spatial resolution (optical)
- High spatial resolution (optical)
- Synthetic Aperture Radar
- LiDAR

MODIS Land Cover Map



Landsat Land Cover Map



Sources: USGS 2015, GLS dataset; Bodart et al. 2011; and Raši et al. 2011.

Remote Sensing Data Sources

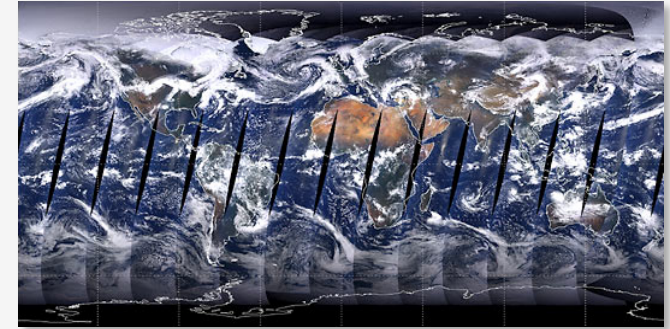
Considerations

- What **geographical, phenological, and atmospheric** (especially persistent cloud cover) conditions exist?
- What are the **spectral regions**, and bands within them, and how do these relate to the potential for distinguishing the land-cover types of interest, and changes among them?
- What is the **spatial resolution** of the data and how appropriate is it, relative to the scale of the land-cover changes to monitor?
- What is the **temporal resolution** in terms of potential frequency of acquisition of non-cloudy observations compared to the desired frequency of monitoring?
- What is the **longevity of the image archive length** – does this meet the historical mapping needs?
- What are the **cost implications** of these data in terms of purchase and analysis?
- What are the **future satellite development** and launch commitments?

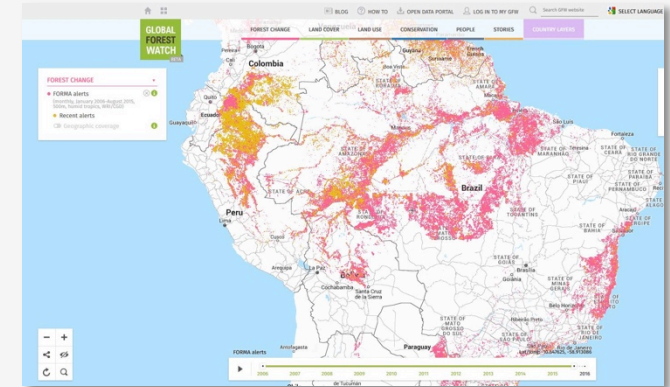
Remote Sensing Data Sources

Coarse Spatial Resolution (Optical)

- Greater than 250m
- Ex: MODIS, CBERS-2
- High temporal resolution useful for early warning and detection of forest clearing and degradation
- Example: FORMA
 - a monitoring system that issues monthly forest loss alerts for the humid tropics.
 - Generates alerts of likely forest clearing activity every 16 days at 500 m spatial resolution (Hammer et al. 2014)



NASA Worldview



FORMAAlerts from Global Forest Watch

Remote Sensing Data Sources

Medium Spatial Resolution (Optical)

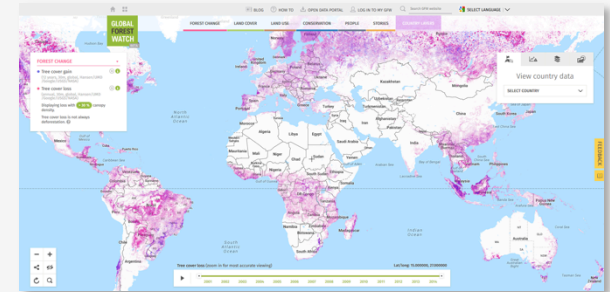
- 10m – 80m spatial resolution
- Most common: Landsat (30m) and more recently, Sentinel 2
- Benefits:
 - Historical archive (early 1980s)
 - Easily accessible and freely available
 - Global coverage
- Limitations: Areas of persistent cloud cover
- Example: Global Forest Watch (Hansen et al. 2013)

Landsat satellite



Credit: NASA

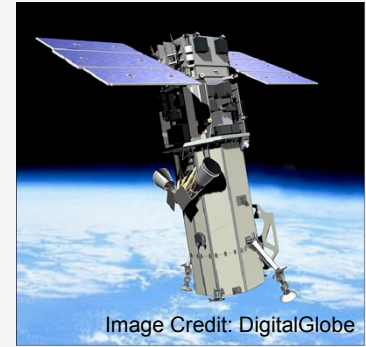
Global Forest Watch



Remote Sensing Data Sources

High Spatial Resolution (Optical)

- Better than 10m spatial resolution
- Examples: Worldview 2 and 3
- Primarily used for accuracy assessment, sampling transects, or hot spot assessment
- Benefits
 - Forest activity data can be monitored more accurately and with greater differentiation
- Limitations
 - Higher acquisition and processing costs
 - Spatial and temporal coverage may not be adequate

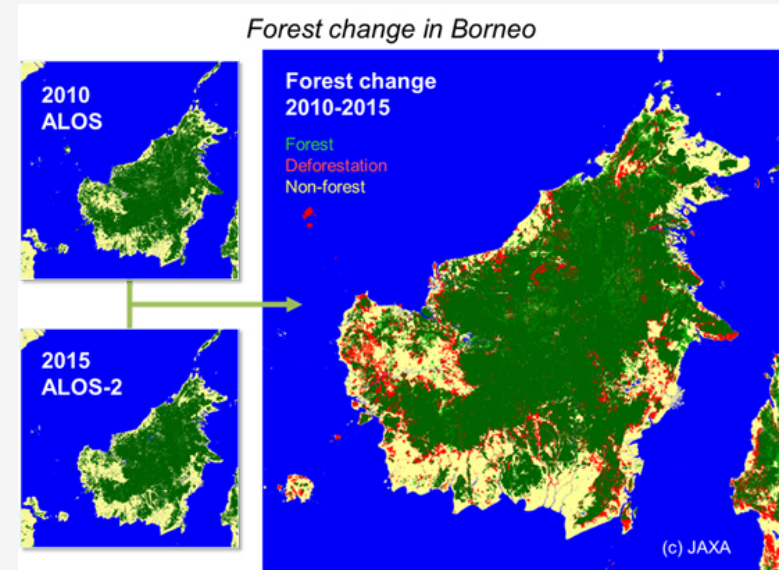


Nilo Forest Reserve, Tanzania. Credit: Digital Globe and Norsk Regnesentral

Remote Sensing Data Sources

Synthetic Aperture Radar

- Two types: C-band and X-band SAR (shorter wavelengths) and L-band SAR (longer wavelengths)
- Can detect forest/non-forest and changes
- Benefits:
 - Useful in areas of persistent cloud cover
 - Can provide information on forest structure; complementary to optical data
- Limitations:
 - Difficult to process
 - Not currently used operationally

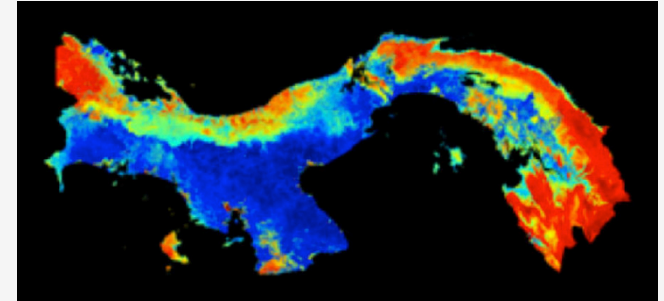


Forest change in Borneo (Masanobu et al. 2014)

Remote Sensing Data Sources

LiDAR

- Provides information on forest structure (e.g. tree height, canopy volume) and biomass
- Currently acquired using aircraft platform – no operational LiDAR satellites
- Benefits
 - Provides detailed information of forest structure
 - Verification of biomass estimates, reduces need for ground sampling
- Limitations
 - Expensive to acquire & process



National carbon map of Panama by integrating field data with satellite imagery and LiDAR (Carnegie Institution, 2013). Credit: Carnegie Institution.

An aerial photograph of a coastline with a semi-transparent circular overlay. The overlay features a grayscale image of a mountain peak with a bright, snow-covered summit. The text 'Pre-processing Requirements' is centered within the overlay, with a horizontal line extending from its left side.

Pre-processing Requirements

Satellite Data Pre-Processing

Overview

- Necessary because it allows satellite observations over different time periods to be compared to each other
- Geometric Corrections (orthorectification)
 - Corrects for angle of view of the satellite sensor
 - Corrects for high relief terrain
- Radiometric corrections
 - Corrects for different atmospheric conditions between multi temporal images
- Satellite imagery is often available with both corrections

Satellite Data Pre-Processing

Geometric Correction

- Most important for detecting change over time using multi-temporal satellite imagery
- Image alignment
 - Images need to be aligned
 - Can be done using image processing software (i.e. ERDAS imagine, ENVI, etc.)
- Image distortion due to scanning system motion, platform instability, or high relief terrain
 - More apparent in aerial photographs than in satellite imagery
 - Use of a Digital Elevation Model (DEM) required for correction
 - Needs specialized software
- Most satellite imagery has been geometrically corrected and projected to a geographic reference system. **It is always good to check.**

Satellite Data Pre-Processing

Radiometric Correction

- The pixel values of a single date image are dependent on the viewing geometry of the satellite, the location of the sun and specific weather and atmospheric conditions.
- Radiometric correction enables comparison of one image to another (of multiple images for large regions and for multi-date images of the same region)
- “Raw” pixel values are converted to surface reflectance using various methods but satellite imagery (Landsat, MODIS) can now be acquired already corrected.

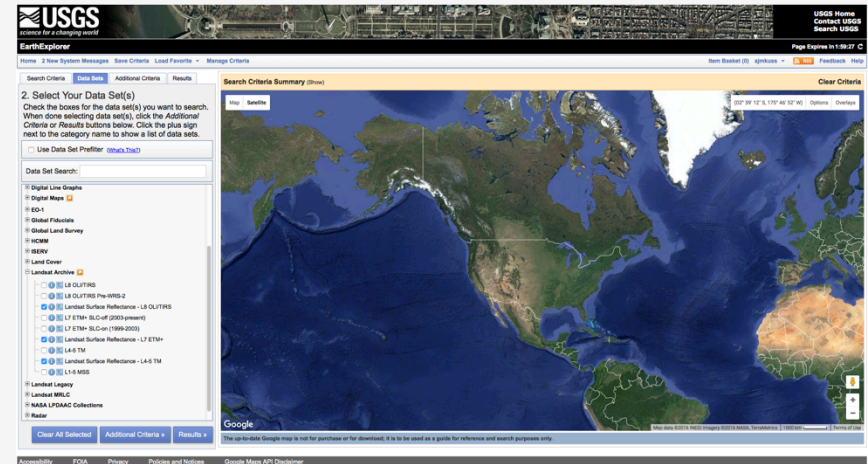


Subsets of a Landsat image displaying (A) natural color; (B) top-of-atmosphere correction; and (C) surface reflectance. Credit: USGS

Satellite Data Pre-Processing

Landsat Surface Reflectance Products

- Surface Reflectance products generated from the Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS)
 - Originally developed by NASA
- Available from EarthExplorer:
 - <http://earthexplorer.usgs.gov>

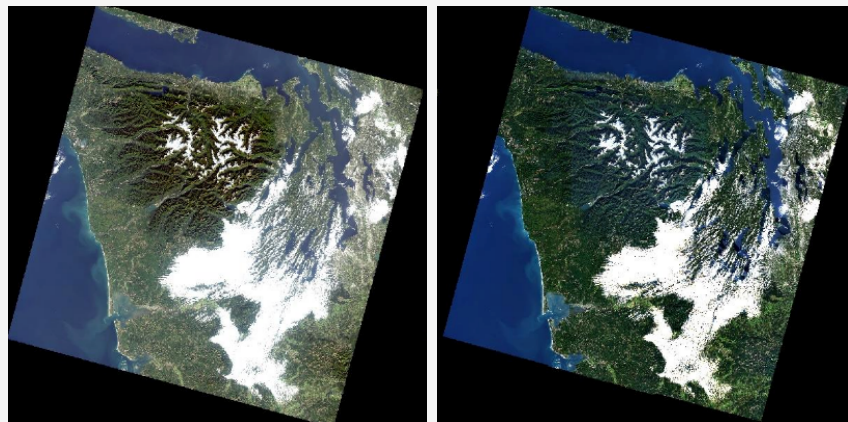


Landsat 4-7 and 8 Surface Reflectance Products Available from EarthExplorer

Satellite Data Pre-Processing

Landsat Surface Reflectance Products Caveats

- Products considered provisional
- Landsat 7 images not gap-filled
- Usefulness of surface reflectance products reduced in:
 - Hyper-arid or snow-covered regions
 - Low sun angle conditions
 - Coastal regions
 - Areas with extensive clouds
- Panchromatic band (ETM+ Band 8) not processed
- Specific date ranges: Landsat 4, 5, 7



Example of the unprocessed Landsat image (top) and the LEDAPS processed Landsat image (right). Credit: USGS

An aerial photograph of a coastline with a semi-transparent circular overlay. The overlay contains a grayscale image of a mountain peak, likely Mount Fuji, with a bright white summit. The background shows a blue ocean on the left, a white sandy beach, and a green, forested land area on the right.

Image Classification and Change Detection

Image Classification

Overview

- Used for mapping forest/non-forest, land cover, or forest stratification
- There are many methods: visual interpretation, pixel-based (supervised, unsupervised), and object-based
- For improved results, often needs ground and/or other ancillary information (topographic or climatic data)
- Needs specialized software (commercial or open source) and training

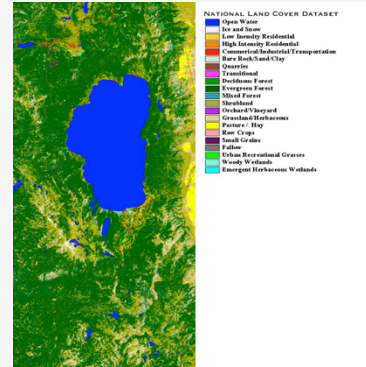
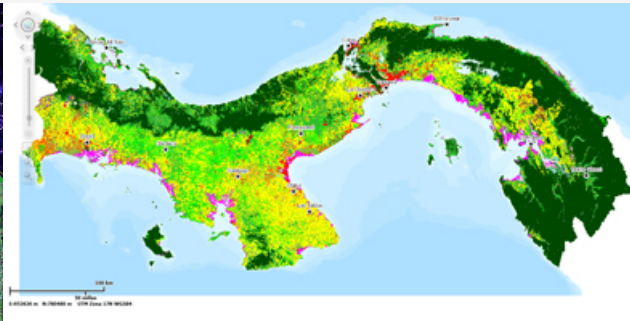
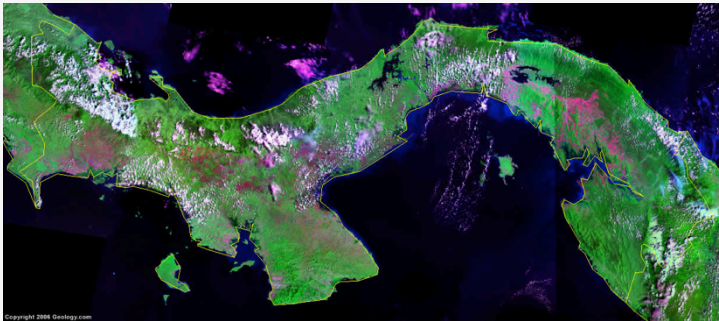


Image Classification

Land Cover Classes

- The image classification processes turns data (pixel values) into information
- That information must be categorized (e.g. forest/non-forest)
- The IPCC Good Practice Guide for Land Use, Land-Use Change and Forestry (GPG-LULUCF 2003) specifies top-level categories as:
 - Forest Land, Cropland, Grassland, Wetlands, Settlements, and Other Land
- Defining classes will depend on the project/program needs and the region



Land cover map of Panama. Credit: ANAM.

Image Classification

Types of Maps

Map products/ classification system	Purpose	Description	Minimum Mapping Unit	Temporal Product Frequency
Forest/Non-Forest	Trend analysis, basis for other products	Extent of all forest types	< 0.5 ha	Annual
Forest Stratification	Provide consistency in biomass density with a stratum for more accurate estimates	Suggested primary stratification: primary forest, modified natural forest, planted forest	< 0.5 ha	Annual
All Land-Use Categories	National baseline mapping	Consider using the UN-FAO Land Cover Classification System	< 0.5 ha	Annual

Image Classification

Summary of types of remote sensing data and their perceived operational status in estimating REDD+ activities

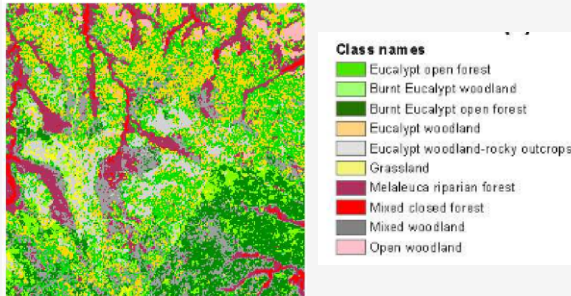
Map Product	Coarse resolution	Medium resolution	High resolution	L-band radar	C-band radar	X-band radar	LiDAR
Forest/Non-forest		Operational	Operational	Operational	R&D	Not used	Occasional use
Forest Stratification	Operational	Operational	Operational	Pre-Operational	R&D	Not used	Occasional use
All land use categories		Operational	Operational	Pre-Operational	R&D	Not used	Occasional use

Image Classification

Approaches

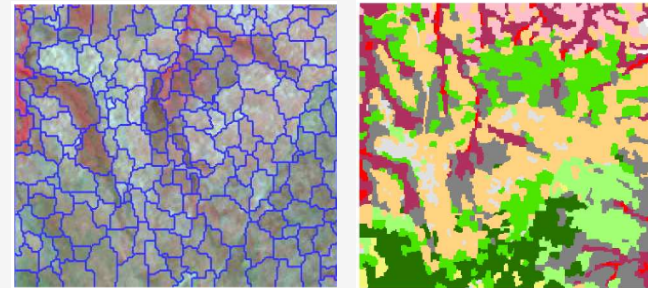
Pixel-based

- Each pixel is grouped into a class
- Useful where there are multiple changes in land use within a short period of time
- Best suited when there is complete data coverage and require methods to ensure time series consistency at the pixel level



Object-based

- Pixels with common spectral characteristics are first grouped together (segmentation)
- Useful for reducing speckle noise in radar images
- Useful for high spatial resolution imagery



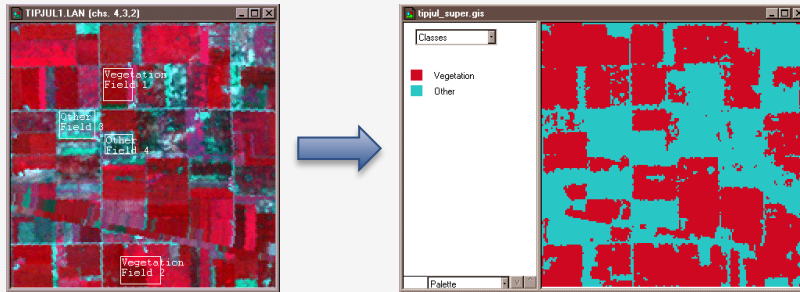
Whiteside et al., (2005), A Comparison of Object-Oriented and Pixel-Based Classification Methods for Mapping Land Cover in Northern Australia

Image Classification

Methods

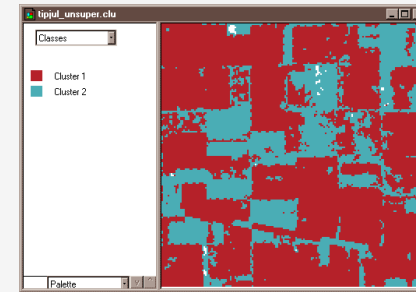
Supervised

- Uses expert-defined areas of known vegetation types (training areas) to tune parameters of classification algorithms
- Algorithm then automatically identifies and labels areas similar to the training data.



Unsupervised

- Uses classification algorithms to assign pixels into one of a number of user-specified class groupings
- Interpreters assign each of the groupings of pixels a value corresponding to a land cover class



Credit: David DiBiase, Penn State Department of Geography

Image Classification

Supervised Method

Supervised classification requires the analyst to select training areas where they know what is on the ground and then digitizes a polygon within that area

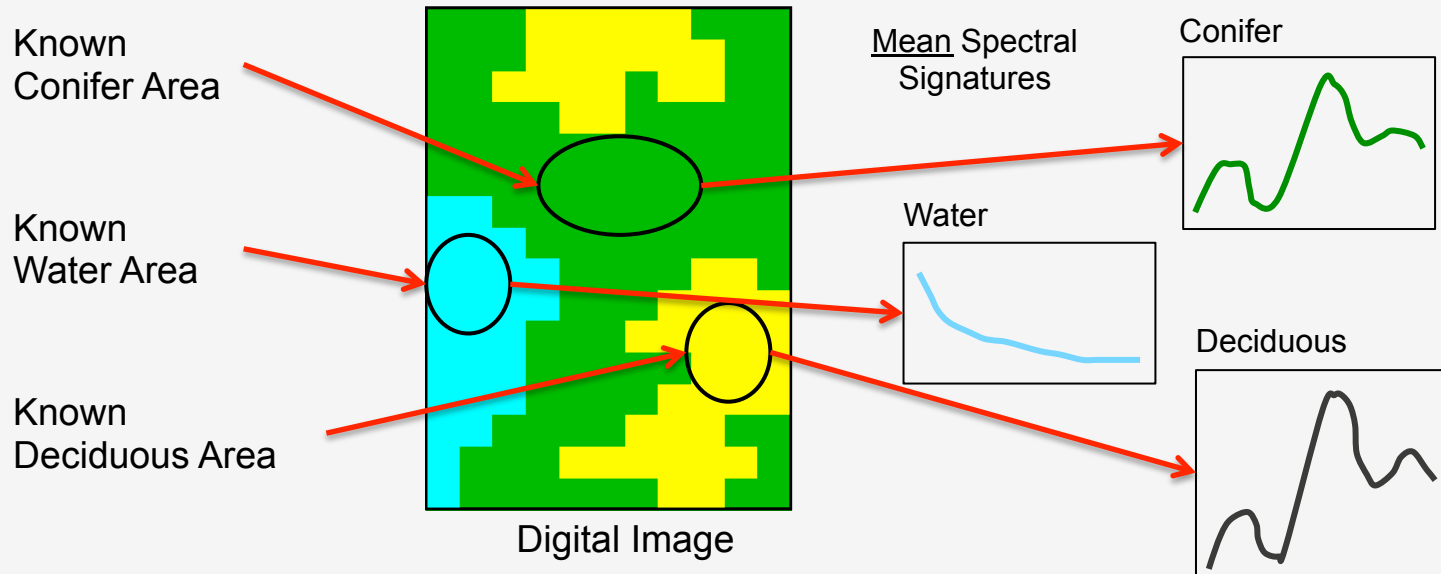
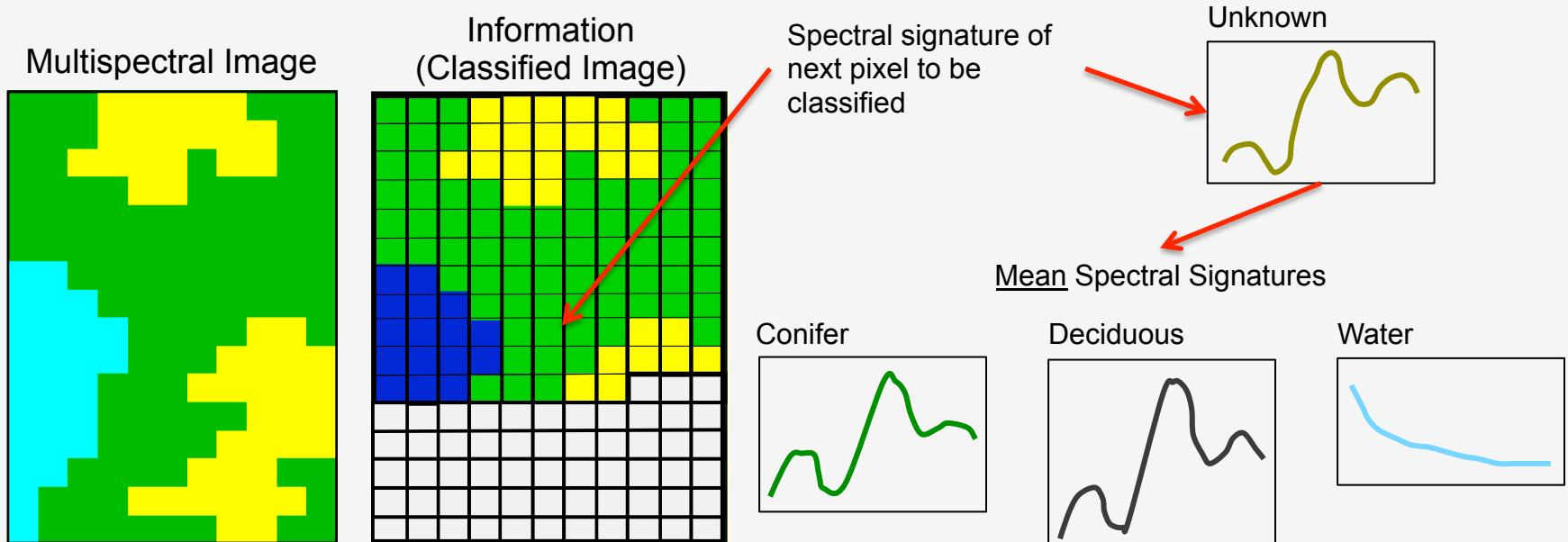


Image Classification

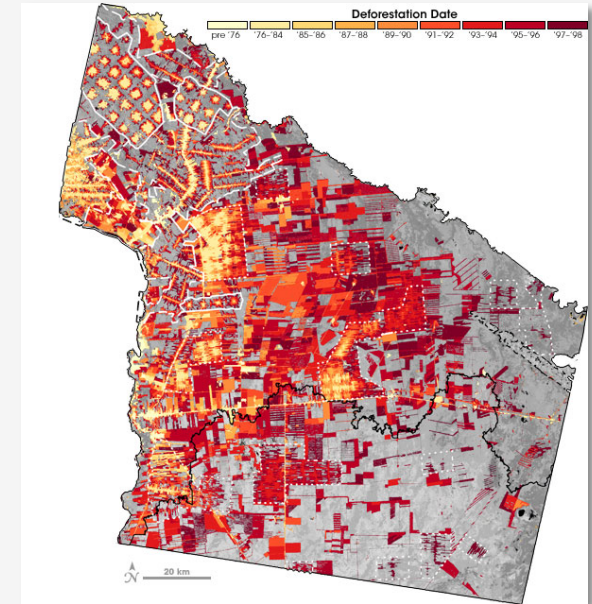
Supervised Method

The spectral signature of each pixel in the image gets matched with the training signatures and the image is classified accordingly



Change Detection

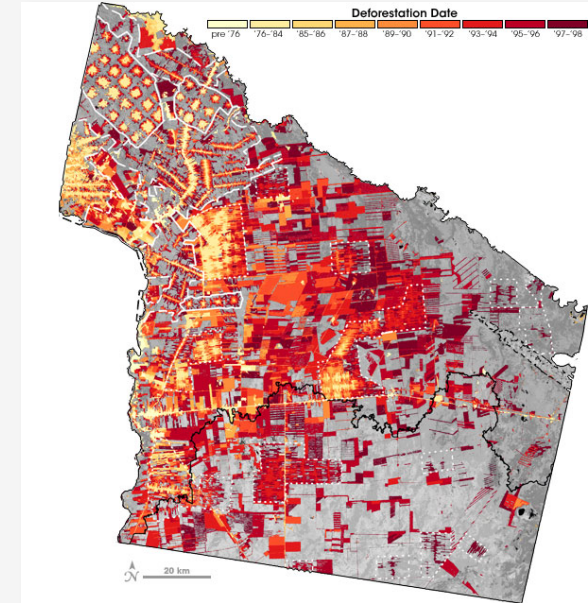
- Activities that cause degradation of carbon stocks within forests and are detectable by satellite imagery
 - tree harvesting (legal and illegal)
 - fire
- Recommend using Landsat-type data for monitoring forest cover changes every 5 to 10 years; although new automated techniques enable annual change detection.
- Many different methods:
 - Visual interpretation
 - Multi-date image segmentation
 - Digital classification techniques
 - Pixel trajectory techniques



Progress of deforestation in Tierra Bajas, Bolivia. Areas deforested before 1976 are yellow, while areas cleared from 1997-98 are dark red.

Change Detection

- Activities that cause degradation of carbon stocks within forests and are detectable by satellite imagery
 - tree harvesting (legal and illegal)
 - fire
- Recommend using Landsat-type data for monitoring forest cover changes every 5 to 10 years; although new automated techniques enable annual change detection.
- Many different methods:
 - Visual interpretation
 - Multi-date image segmentation
 - Digital classification techniques
 - Pixel trajectory techniques

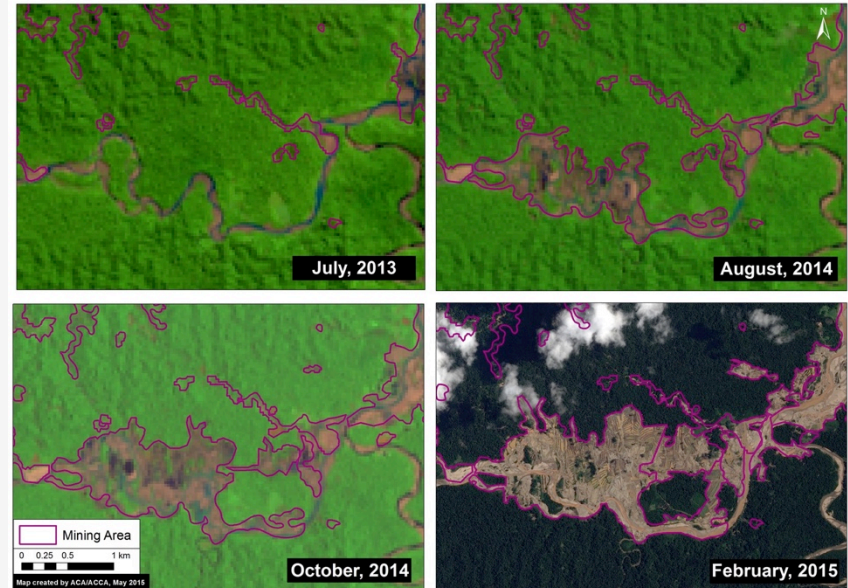


Progress of deforestation in Tierra Bajas, Bolivia. Areas deforested before 1976 are yellow, while areas cleared from 1997-98 are dark red.

Change Detection

Methods: Visual Interpretation

- Visual interpretation involves the delineation of change on a computer screen (rather than a paper map)
- This allows production of results that are automatically in digital form
- This method works best if image analysis tools and experiences are limited



Deforestation along the Upper Malinowski in Peru due to mining from Landsat and SPOT 7. Credit: Amazon Conservation Association

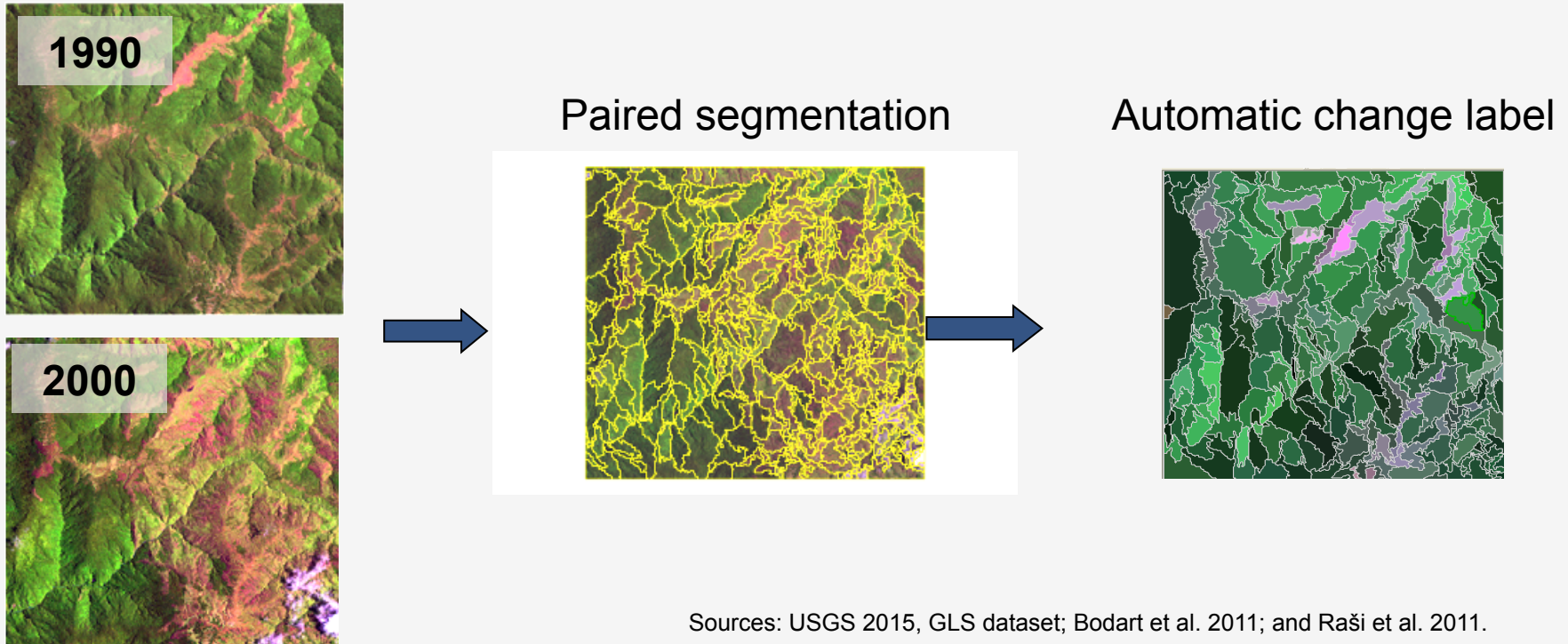
Change Detection

Methods: Multi-date image segmentation

- Automated segmentation reduces processing time and increases detail
- It is objective and repeatable
- It delineates changed areas as separate segments
- Ideally, analysis process would include:
 - Multidate image segmentation on image pairs
 - Training area/class signature selection
 - Supervised clustering of individual images
 - Visual verification and potential editing

Change Detection

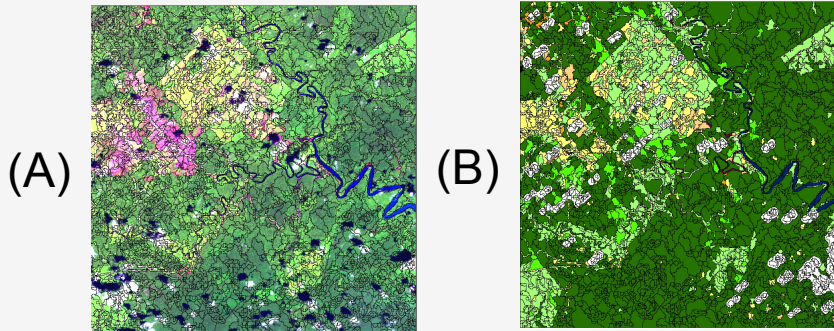
Example of multi-date segmentation



Change Detection

Digital Classification of Image Segments

- Two supervised object classifications run separately on the two multi-date images are recommended instead of a single supervised object classification on the image pair.
- A common predefined standard training data set of spectral signatures for each type of ecosystem should ideally be used to create initial automated forest maps.
- Supervised classification approaches are considered more efficient in the case of a large number of images than unsupervised clustering techniques.



(A) Multi-temporal segmentation from two images: 2000-2010

(B) Classification of the year 2000 image based on the supervised signatures.

Sources: USGS 2015, GLS dataset; Bodart et al. 2011; and Raši et al. 2011

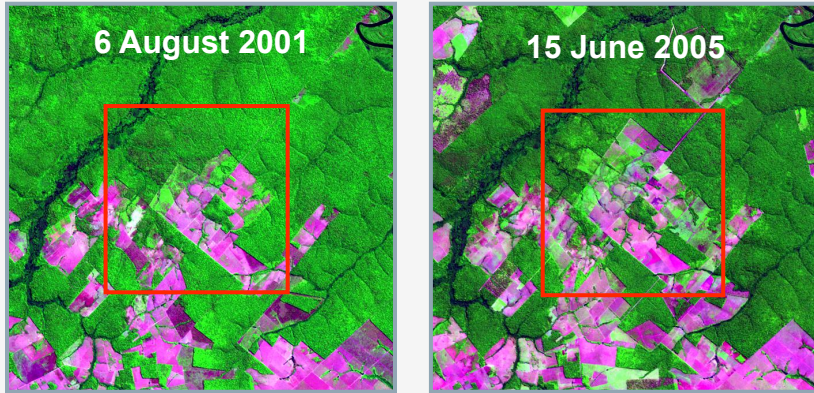
Legend

- Tree cover
- Shrub and regrowth
- Grass, herbaceous

Change Detection

Example of multi-date segmentation approach: Brazil forest cover

Landsat-5 TM imagery



Land cover maps of 2001 to 2005



Legend

- Tree cover
- Tree cover mosaic
- Other wooded land
- Other land cover

Sources: USGS 2015, GLS dataset; Eva et al. 2012.

An aerial photograph of a lush green forested mountain. A semi-transparent white rectangular box is overlaid on the left side of the image, containing the title text. The background shows the intricate patterns of the forest canopy and the rugged terrain of the mountain.

National Forest Monitoring System – Remote Sensing Sustainability Considerations

National Forest Monitoring System

Sustainability Considerations

- Longevity of satellite mission providing data underlying Activity Data generation and future sensor launch and data acquisition strategy
 - Example: Landsat continuity
- Consistency of methods used to produce Activity Data
- Plans for archiving imagery and data products for transparency



NASA's Carbon Mapper

- Developed by NASA's Carbon Monitoring System (CMS)
- Beta version
- Common platform for visualizing carbon globally
- Features
 - Mapping and data visualizations
 - Regional carbon summaries
 - Time series plots of carbon flux and stocks
- Website: <https://cmsun.jpl.nasa.gov>

A banner image featuring a satellite map of North America with a color gradient from dark purple to green, representing carbon density. The text "Carbon Mapper" is in large white font, with "beta" in a smaller, lighter font to its right. Below the text is a purple button with the text "Start Exploring" in white.

Carbon Mapper^{beta}

Start Exploring

ANNUAL 2005



48°26'53"N, 115°29'12"W EPSG:4326

500 km

Active Datasets ▼

- | | |
|--|--------|
| ▼ Coastlines, Borders, Roads
Overlays | ✕
i |
| ▼ AGB Carbon Global
Stock – Global Forest Carbon Stocks | ✕
i |
| ▼ Land / Water Map
Basemap | ✕
i |

ANNUAL 2005

48°26'53"N, 115°29'12"W EPSG:4326

500 km

Active Datasets ▼

- | | |
|--|--------|
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Overlays | ✕
i |
| ▼ AGB Carbon Global
Stock – Global Forest Carbon Stocks | ✕
i |
| ▼ Land / Water Map
Basemap | ✕
i |

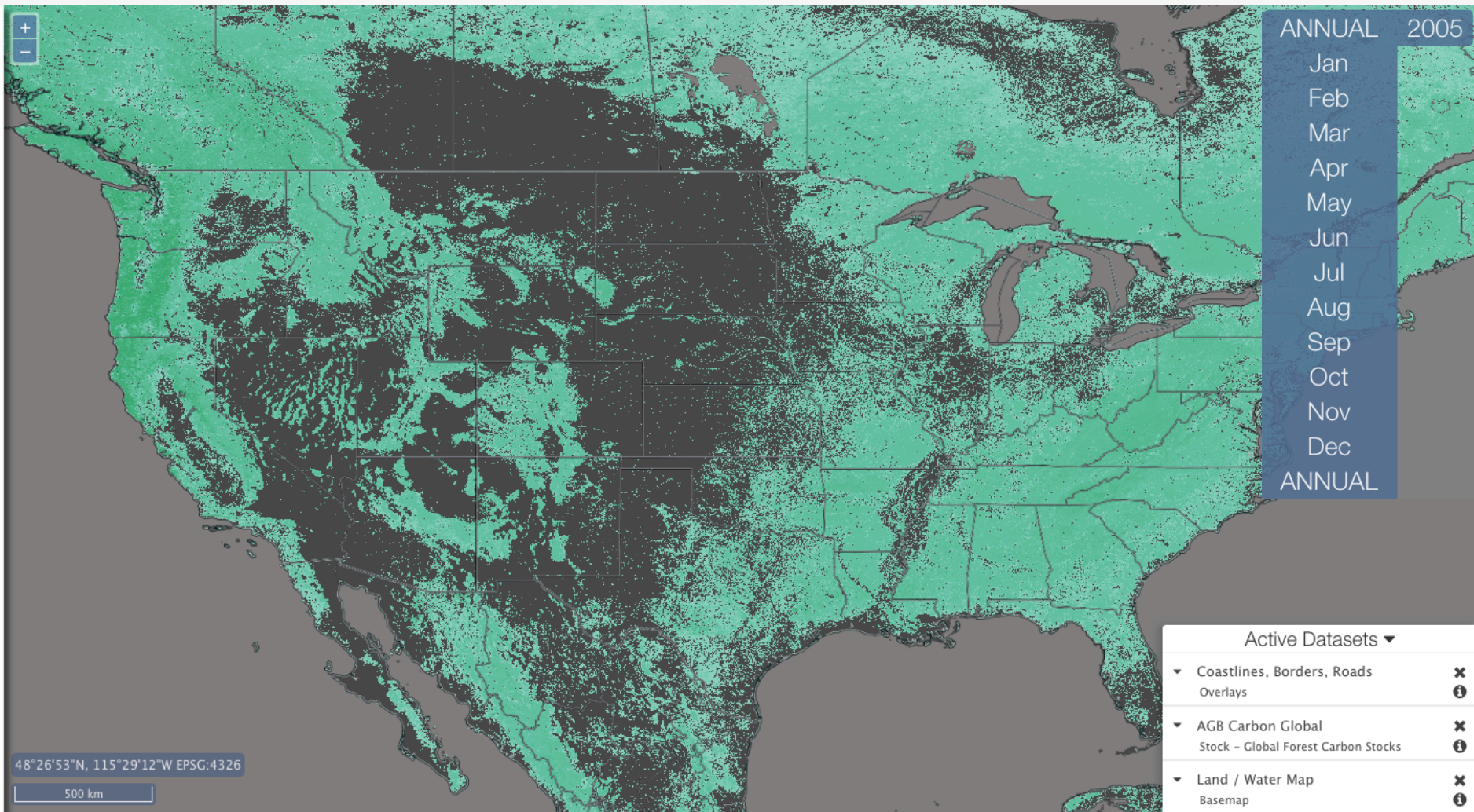
ANNUAL 2005

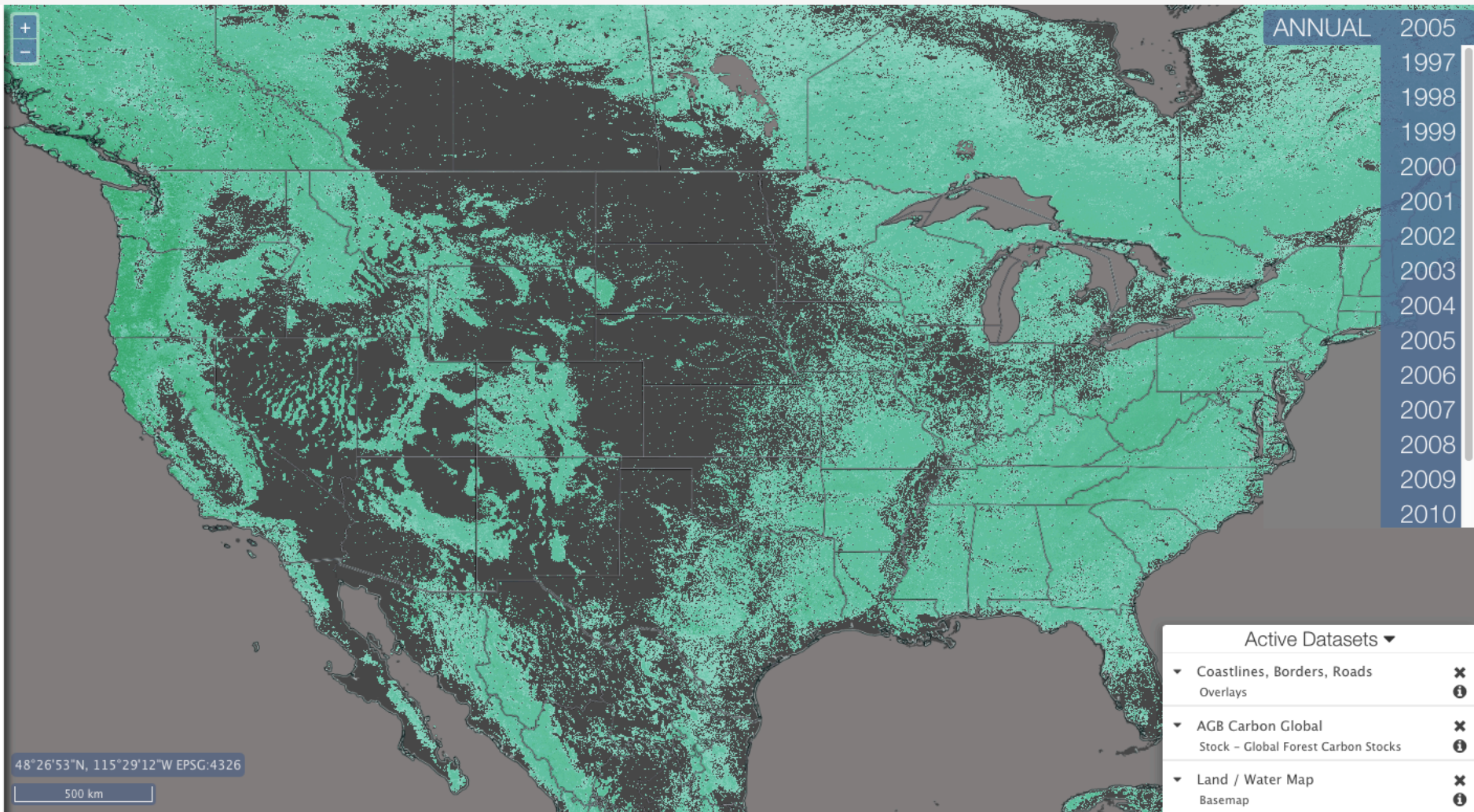
48°26'53"N, 115°29'12"W EPSG:4326

500 km

Active Datasets ▼

- | | |
|--|--------|
| ▼ Coastlines, Borders, Roads
Overlays | ✕
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Stock – Global Forest Carbon Stocks | ✕
i |
| ▼ Land / Water Map
Basemap | ✕
i |





ANNUAL 2005



48°26'53"N, 115°29'12"W EPSG:4326

500 km

Active Datasets ▼

- | | |
|--|--------|
| ▼ Coastlines, Borders, Roads
Overlays | ✕
i |
| ▼ AGB Carbon Global
Stock – Global Forest Carbon Stocks | ✕
i |
| ▼ Land / Water Map
Basemap | ✕
i |

ANNUAL 2005



48°26'53"N, 115°29'12"W EPSG:4326

500 km

Active Datasets ▼

▼ Coastlines, Borders, Roads
Overlays



▲ AGB Carbon Global
Stock - Global Forest Carbon Stocks



Hover over the legend to view data values



1.00e-6 kg C/m² 1.00e+2

This dataset uses a logarithmic color ramp

▼ Land / Water Map
Basemap



ANNUAL 2005

Global Forest Carbon Stocks

Version

CMS Phase 2 Biomass Pilot – August 2015

Principal Investigator

Sassan Saatchi, Jet Propulsion Laboratory

URL

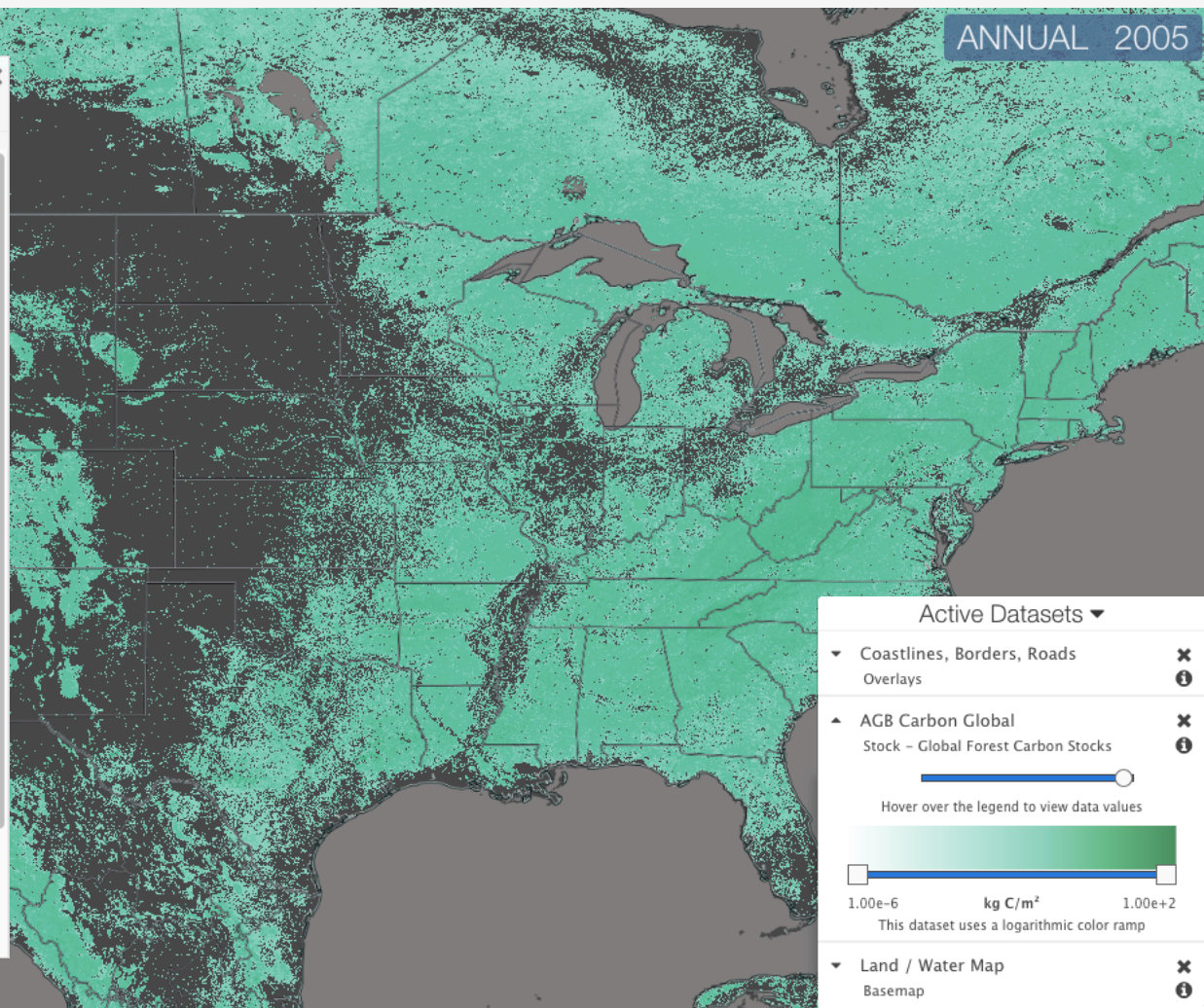
<http://carbon.jpl.nasa.gov/>

Summary

This data set builds on the CMS phase 1 Biomass Pilot project by developing spatial maps for forest carbon stocks in all pools: Above Ground Biomass (AGB), Below Ground Biomass (BGB), Coarse Woody Debris (CWD), forest floor litter (LT), and soil). The native resolution is 1 hectare (100 m) resolution covering forestlands of the Contiguous United States (CONUS) for the period 2005–2010. The spatial resolution of stocks and changes used in the Carbon Calculator website is 100 m.

In phase 1 of the project, the maps were based on GLAS Lidar data and FIA field inventory data and represented the status of forest biomass for the period of 2005 (2004–2006). During the phase 2 of the project, the quality of all maps were improved by integrating a forest type allometry for converting the GLAS data to forest biomass and using the NCLD land cover map to implement the allometry in an algorithmic approach to develop the final GLAS Lidar based map. The final map has been compared with the FIA based map and the differences and uncertainty associated with the pixel level predictions are reported.

500 km



ANNUAL 2005



48°26'53"N, 115°29'12"W EPSG:4326

500 km

Active Datasets ▼

▼ Coastlines, Borders, Roads Overlays	✕ i
▼ AGB Carbon Global Stock – Global Forest Carbon Stocks	✕ i
▼ Land / Water Map Basemap	✕ i

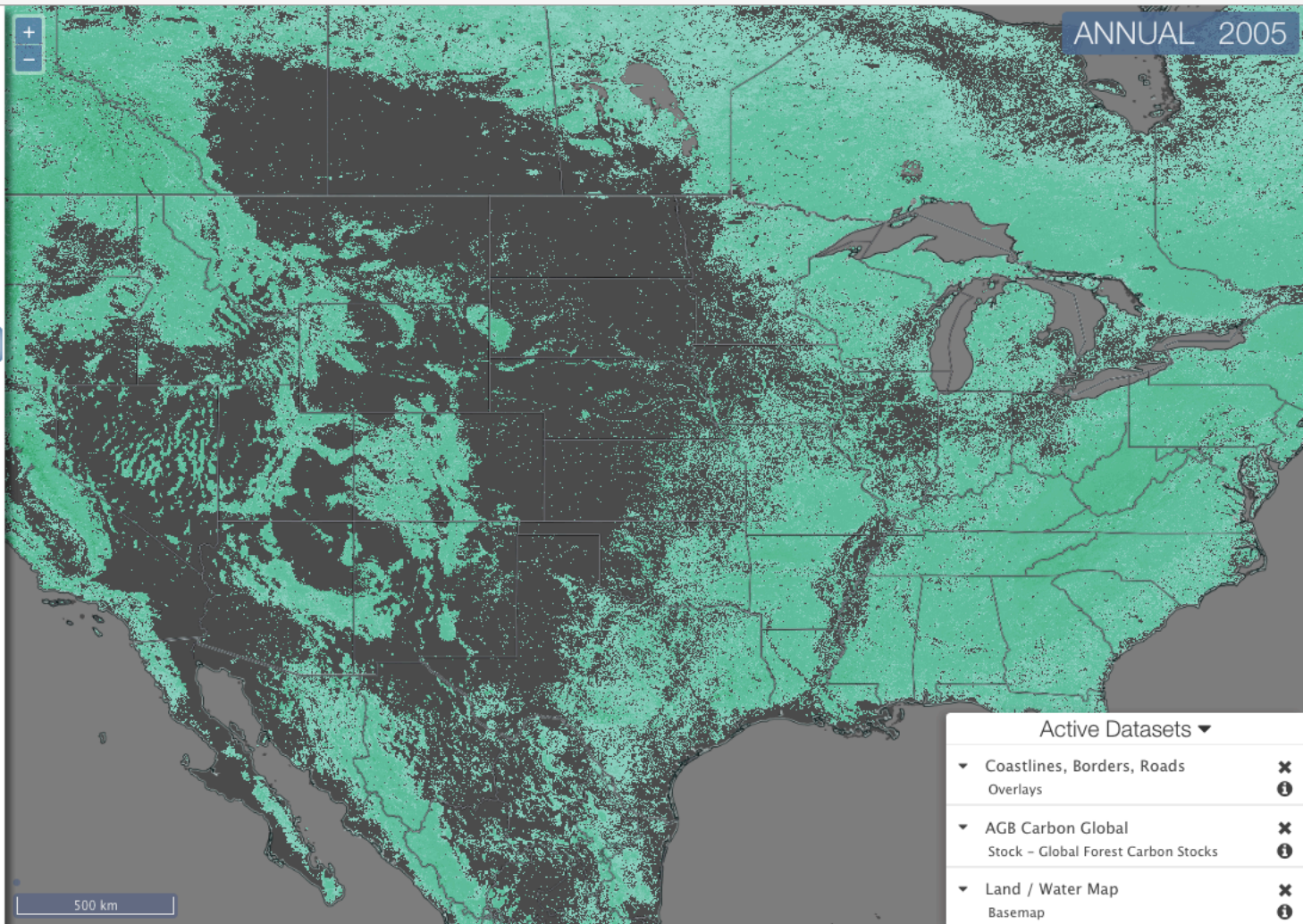


Carbon Mapper

- Flux ⓘ
- Stock ⓘ
- Overlays ⓘ
- Basemap ⓘ



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Active Datasets ▼

- ▼ Coastlines, Borders, Roads Overlays ⓘ
- ▼ AGB Carbon Global Stock - Global Forest Carbon Stocks ⓘ
- ▼ Land / Water Map Basemap ⓘ

Map

Bar Chart

Time Series

[Leave Feedback](#) [Get Involved](#)



Carbon Mapper

Flux



Global Cropland Carbon Flux



2005, 2006, 2007, 2008, 2009, 2010, 2011

Global Fossil Fuel CO2 Flux



1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010

Global Total CO2 Flux



2010, 2011

North America Methane Flux



2010, 2011

US Forest Carbon Flux



2005, 2006, 2007, 2008, 2009, 2010

US Fossil Fuel CO2 Flux



2002

Stock



Overlays



Basemap



Map



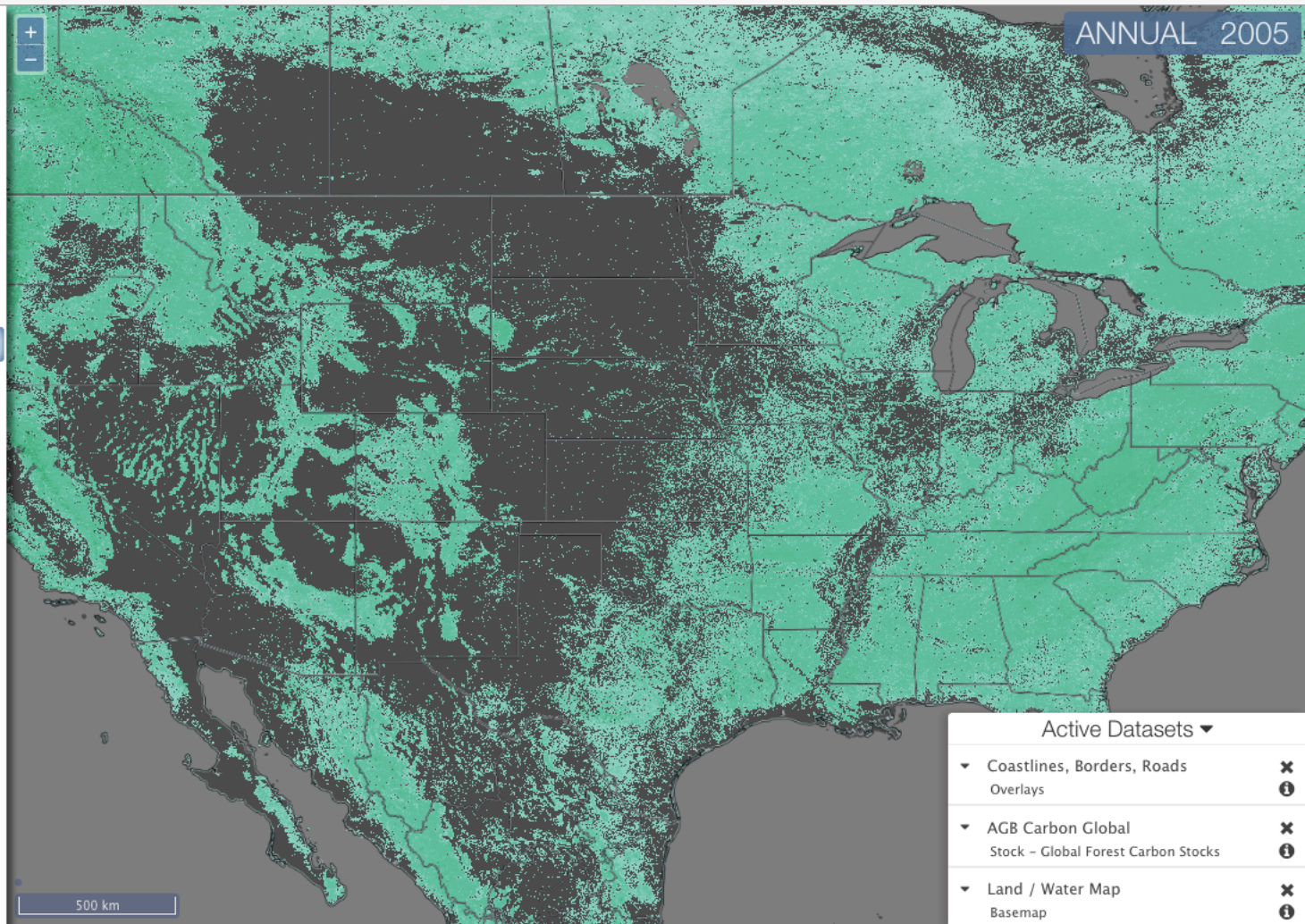
Bar Chart









Time Series

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Active Datasets ▼

- ▼ Coastlines, Borders, Roads Overlays  
- ▼ AGB Carbon Global Stock - Global Forest Carbon Stocks  
- ▼ Land / Water Map Basemap  

ANNUAL 2005



48°26'53"N, 115°29'12"W EPSG:4326

500 km

Active Datasets ▼

▼ Coastlines, Borders, Roads Overlays	✕ i
▼ AGB Carbon Global Stock – Global Forest Carbon Stocks	✕ i
▼ Land / Water Map Basemap	✕ i



Carbon Mapper

Data Scaling

Mass Eq. Unit

Compound Eq. Unit

Unscaled

Unscaled

☐ Standard Notation

Data Examination

Point Data

Box Histogram

Click on a pixel to retrieve data



Map

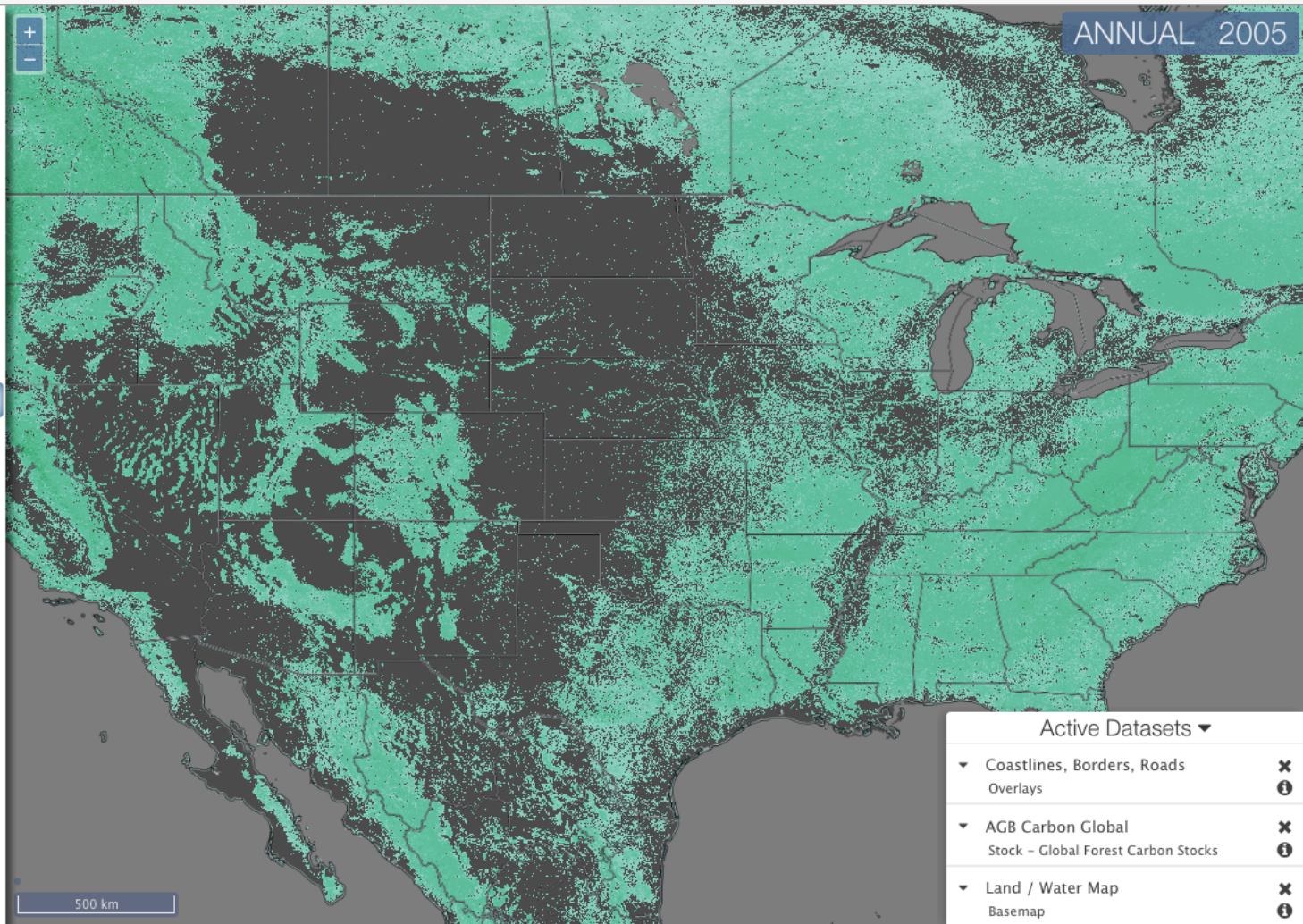
Bar Chart

Time Series

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Active Datasets ▼

▼ Coastlines, Borders, Roads Overlays



▼ AGB Carbon Global Stock - Global Forest Carbon Stocks



▼ Land / Water Map Basemap





Carbon Mapper

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Mass Eq. Unit

Compound Eq. Unit

Unscaled

Unscaled

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Map

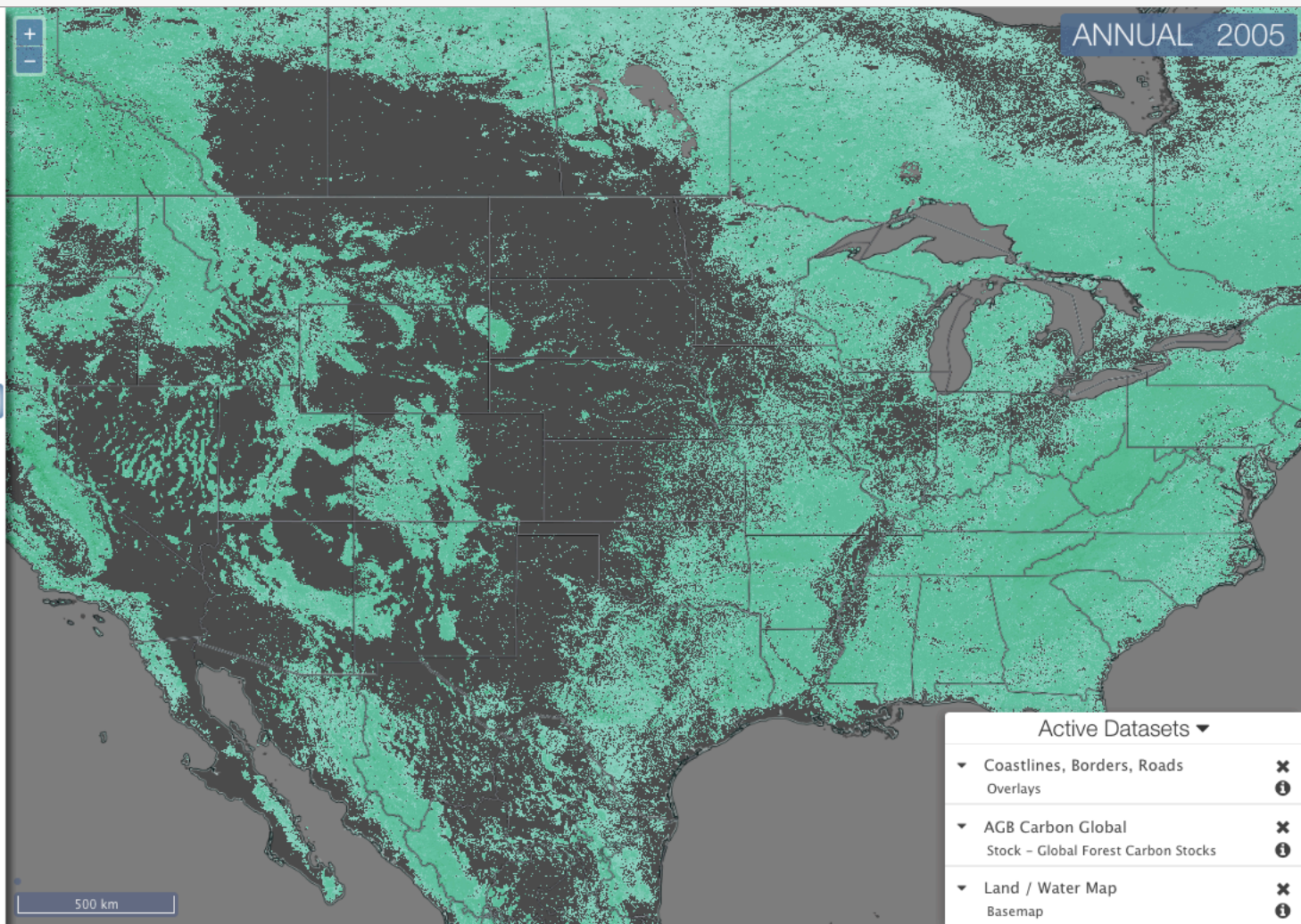
Bar Chart

Time Series

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Active Datasets ▼

- ▼ Coastlines, Borders, Roads Overlays ✕ i
- ▼ AGB Carbon Global Stock - Global Forest Carbon Stocks ✕ i
- ▼ Land / Water Map Basemap ✕ i



Carbon Mapper

Data Scaling

Mass Eq. Unit

Compound Eq. Unit

Unscaled

Unscaled

☐ Standard Notation

Regional Selection

Region:

World

Country:

Export Table

Compare Subregions

Map

Bar Chart

Time Series

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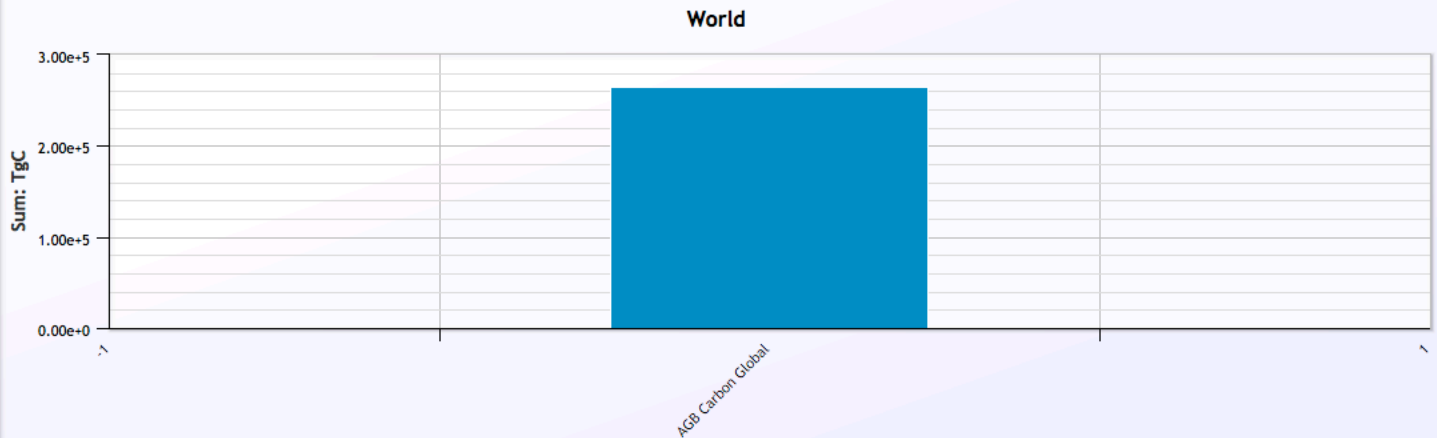
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World
TgC

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	Sum	Mean	Max	Min	Std
AGB Carbon Global	2.65e+5	Unknown	Unknown	Unknown	Unknown

* data entry was generated by Carbon Mapper Team





Carbon Mapper

Data Scaling

Mass Eq. Unit

Compound Eq. Unit

Unscaled

Unscaled

☐ Standard Notation

Regional Selection

Region:

World

Country:

Sort by Name

Sort by Total

Display by Value

Display by Percent

Show Table

Export Table

View Parent Region

Map

Bar Chart

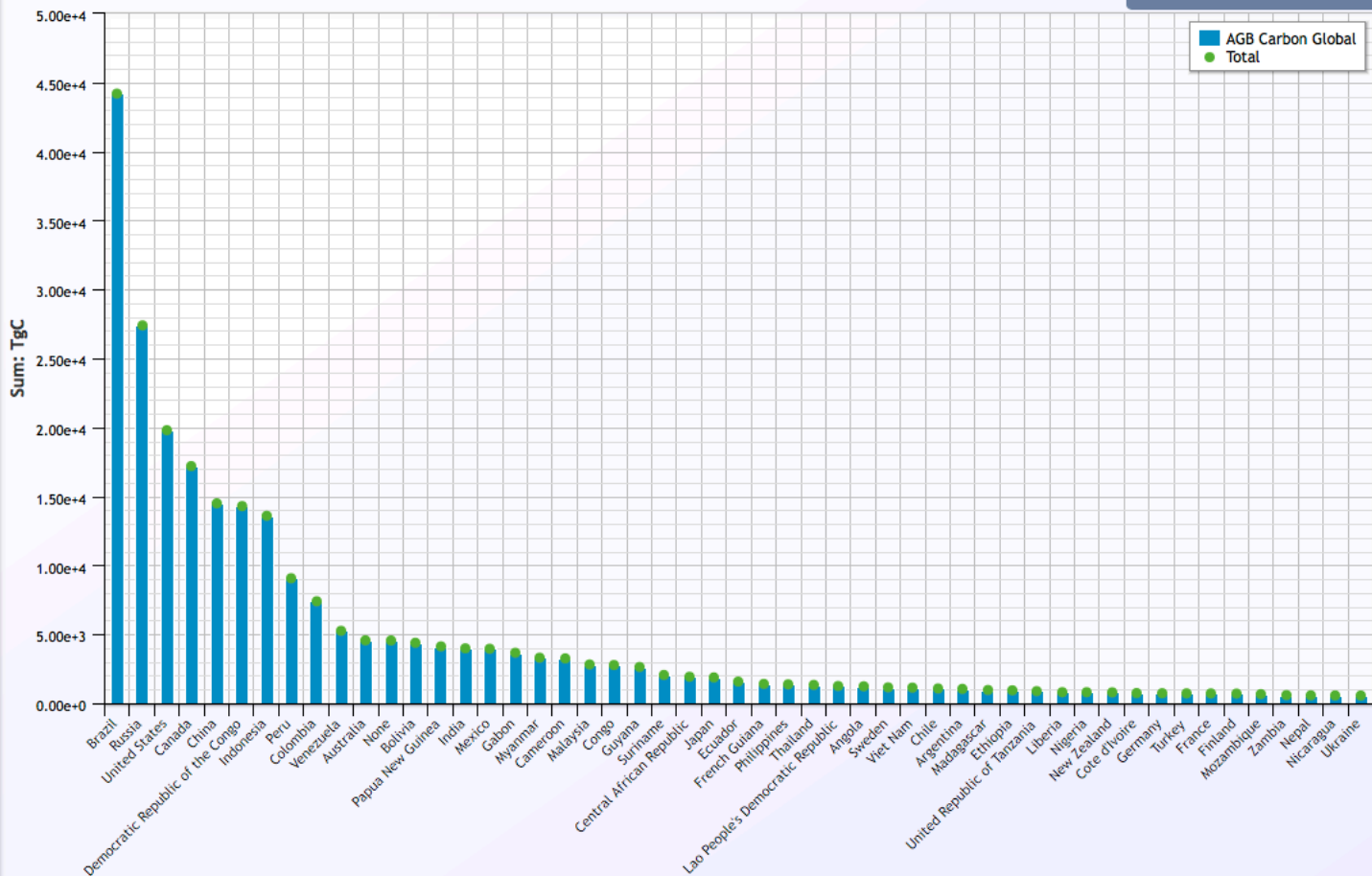
Time Series

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World

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Carbon Mapper

Data Scaling

Mass Eq. Unit

Compound Eq. Unit

Unscaled

Unscaled

☐ Standard Notation

Regional Selection

Region:

World

Country:



Sort by Name

Sort by Total

Display by Value

Display by Percent

Show Table

Export Table

View Parent Region



Map



Bar Chart



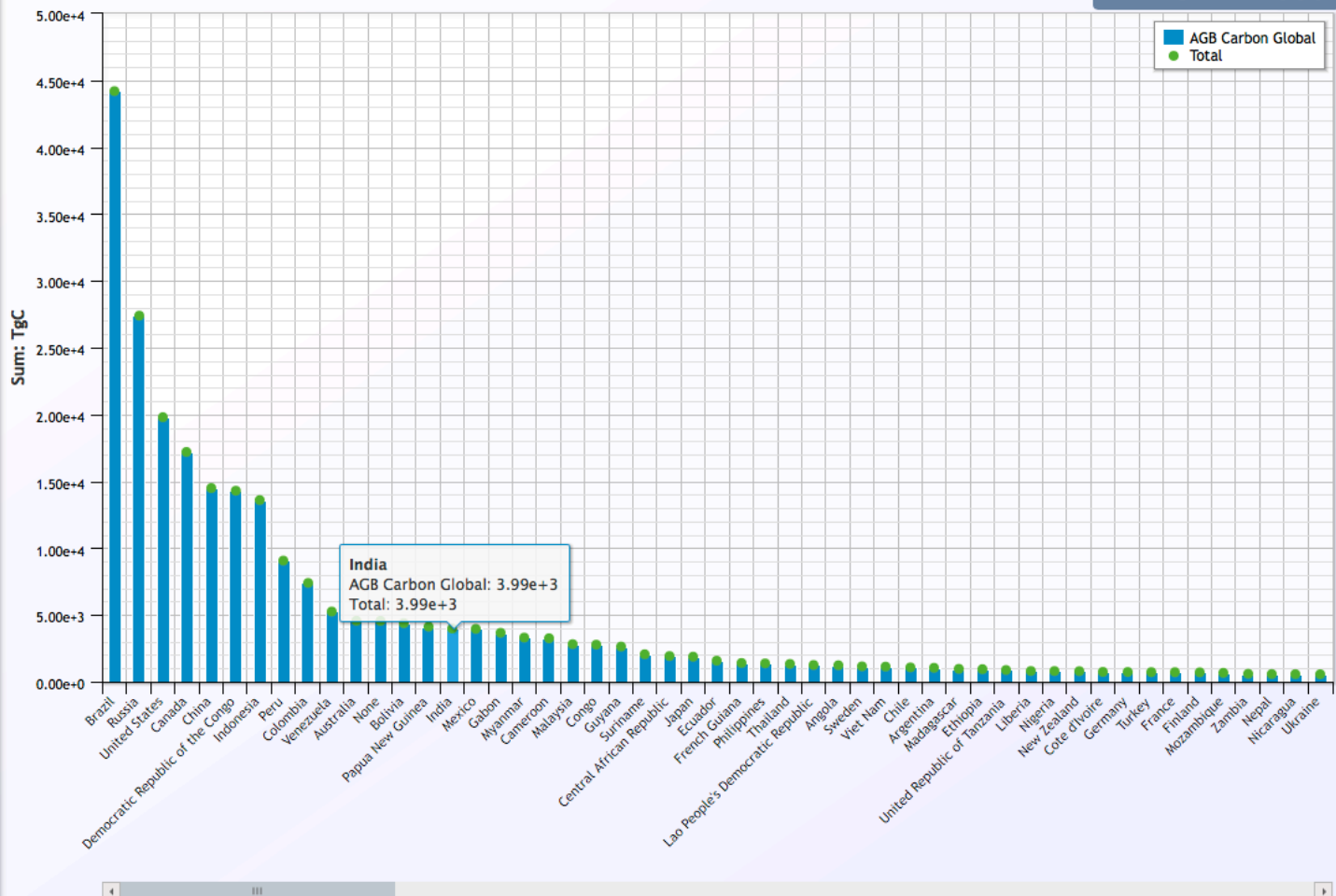
Time Series

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World

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Carbon Mapper

Data Scaling

Mass Eq. Unit

Compound Eq. Unit

Unscaled

Unscaled

☐ Standard Notation

Regional Selection

Region:

World

Country:

Sort by Name

Sort by Total

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Show Table

Export Table

View Parent Region



Map



Bar Chart



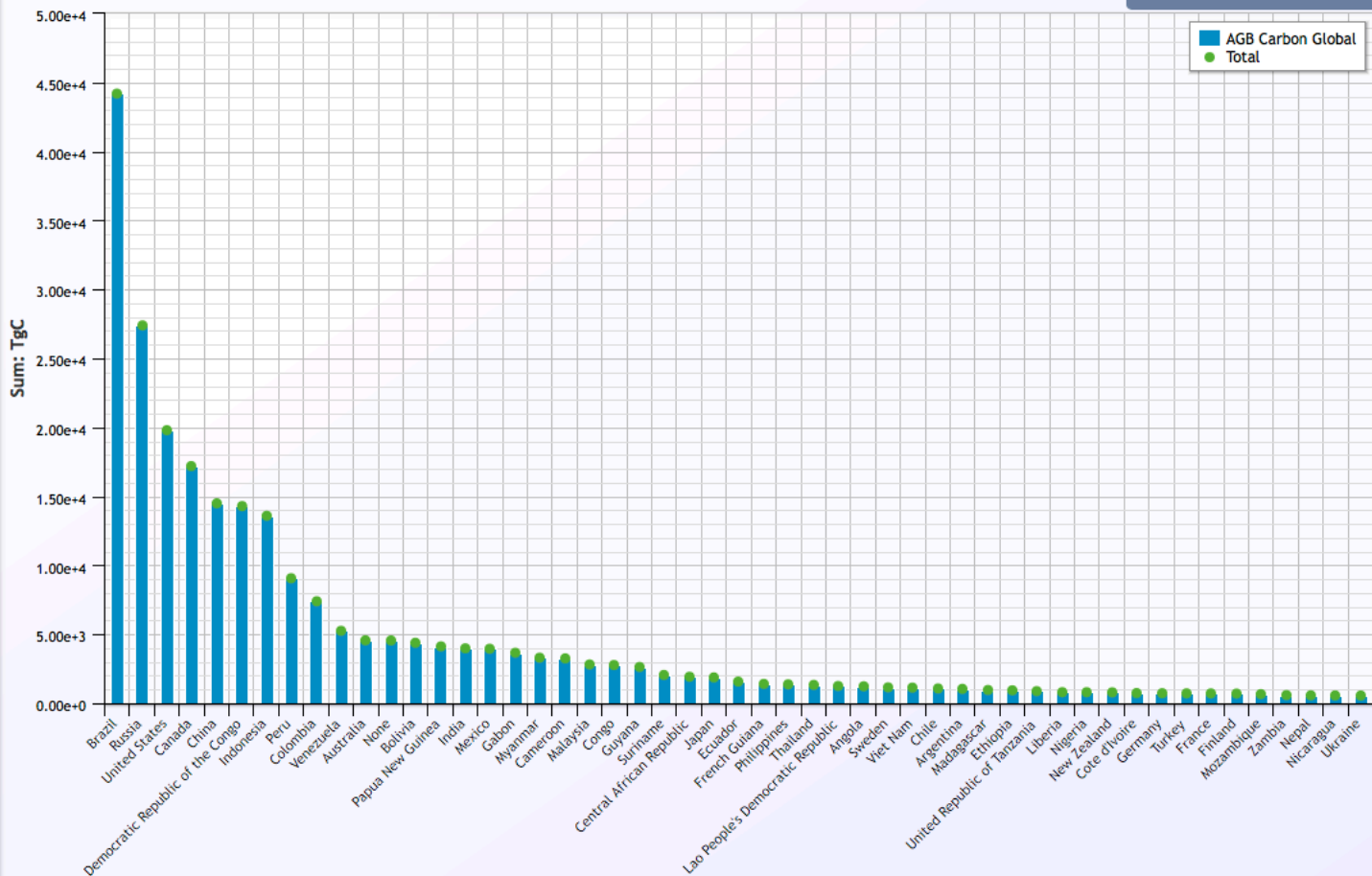
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Carbon Mapper

Data Discovery

What is the distribution of Fossil Fuel CO₂ fluxes by state within the United States? ⓘ

How much carbon flux is there due to Forest Sequestration in California? ⓘ

Compare carbon fluxes associated with crop production and consumption in the United States. ⓘ

How are Forest Carbon stocks distributed within the United States? ⓘ

Compare the changes in CO₂ emissions by sector in India over time. ⓘ

How do CH₄ and CO₂ emissions from fires compare using the AR5 20yr GWP scales in the North American Boreal region? ⓘ

Compare a dataset's regional sum to its uncertainty. ⓘ



Map

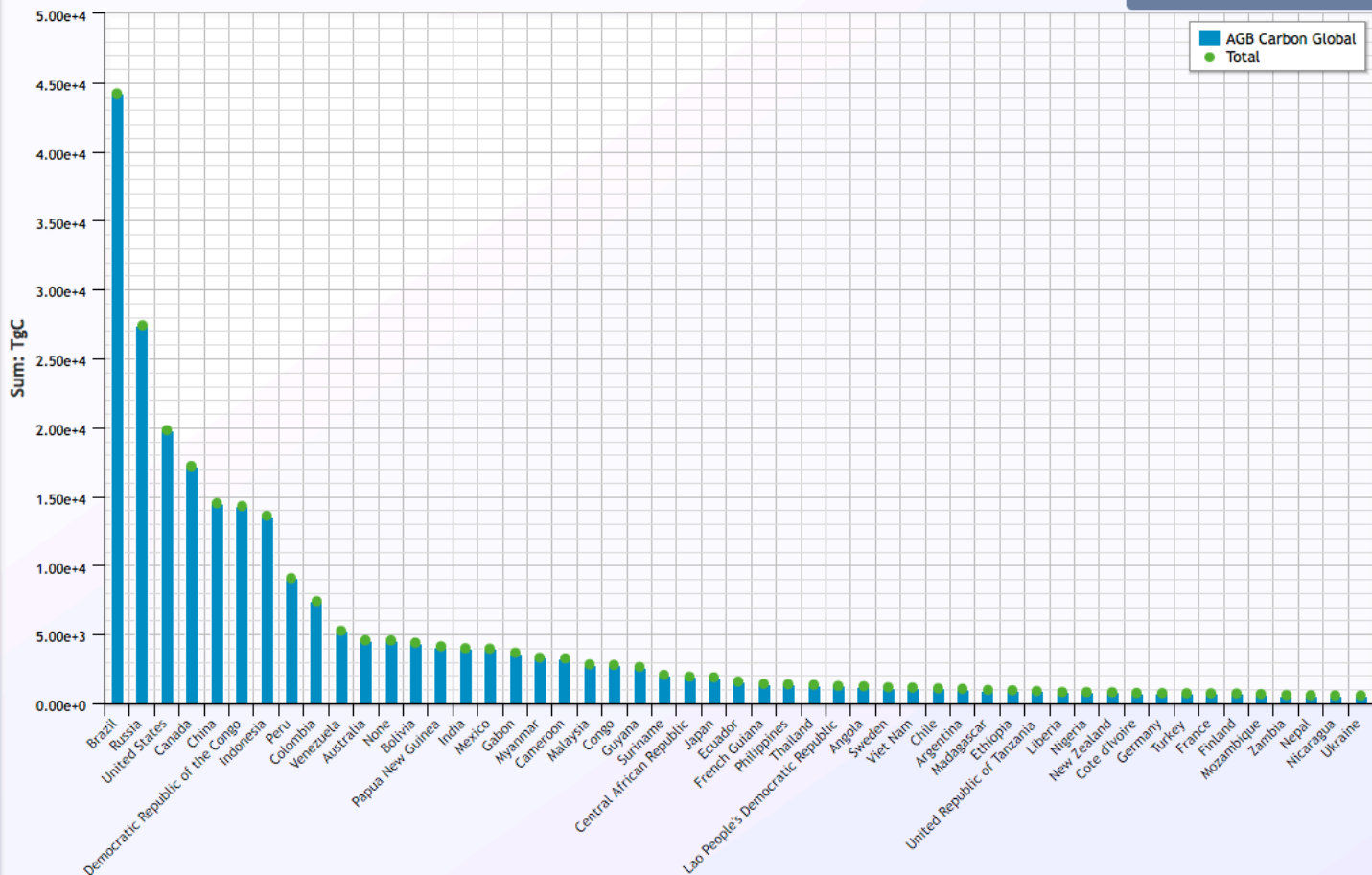
Bar Chart

Time Series

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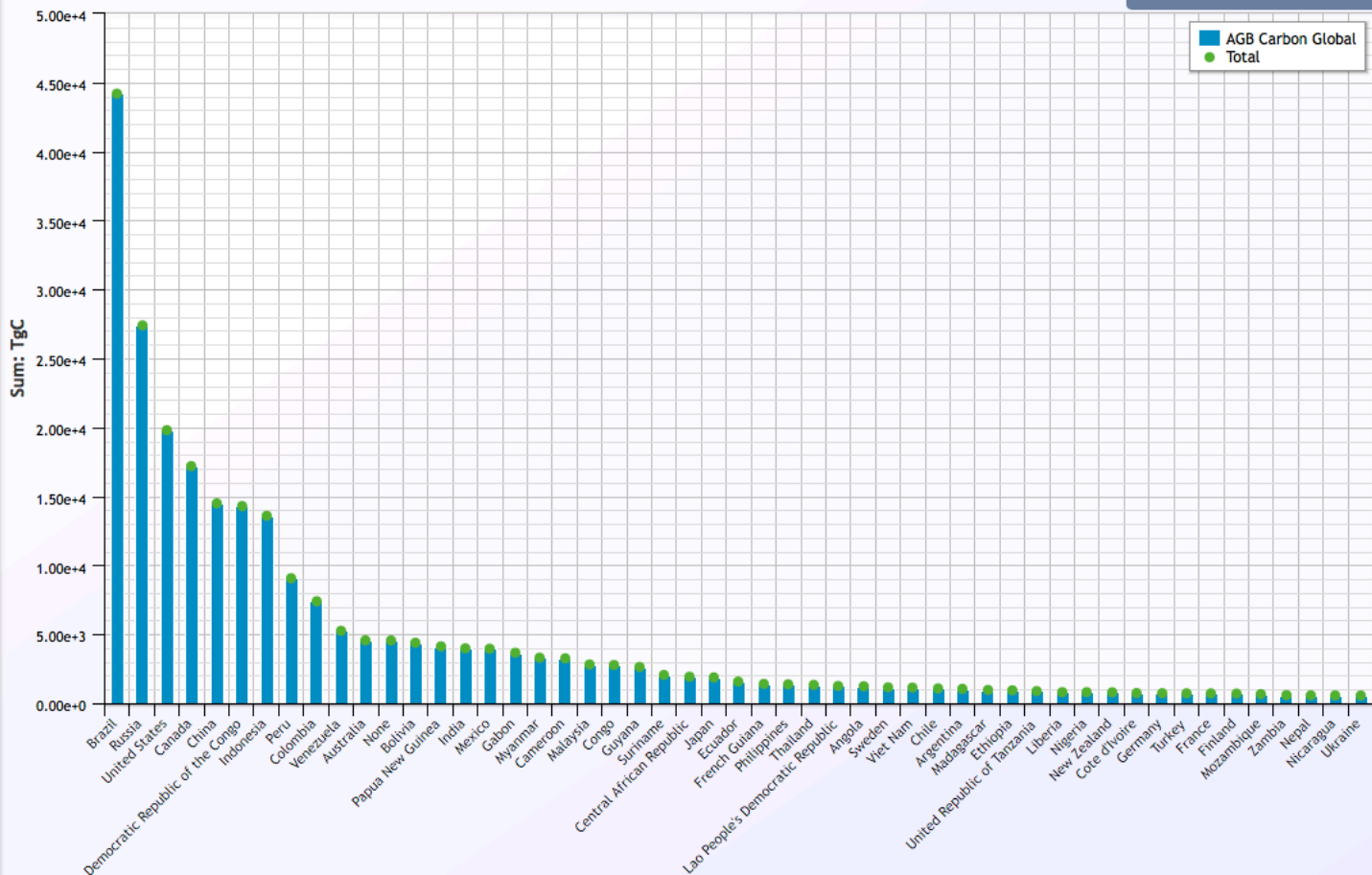
Bar Chart

Time Series

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Carbon Mapper

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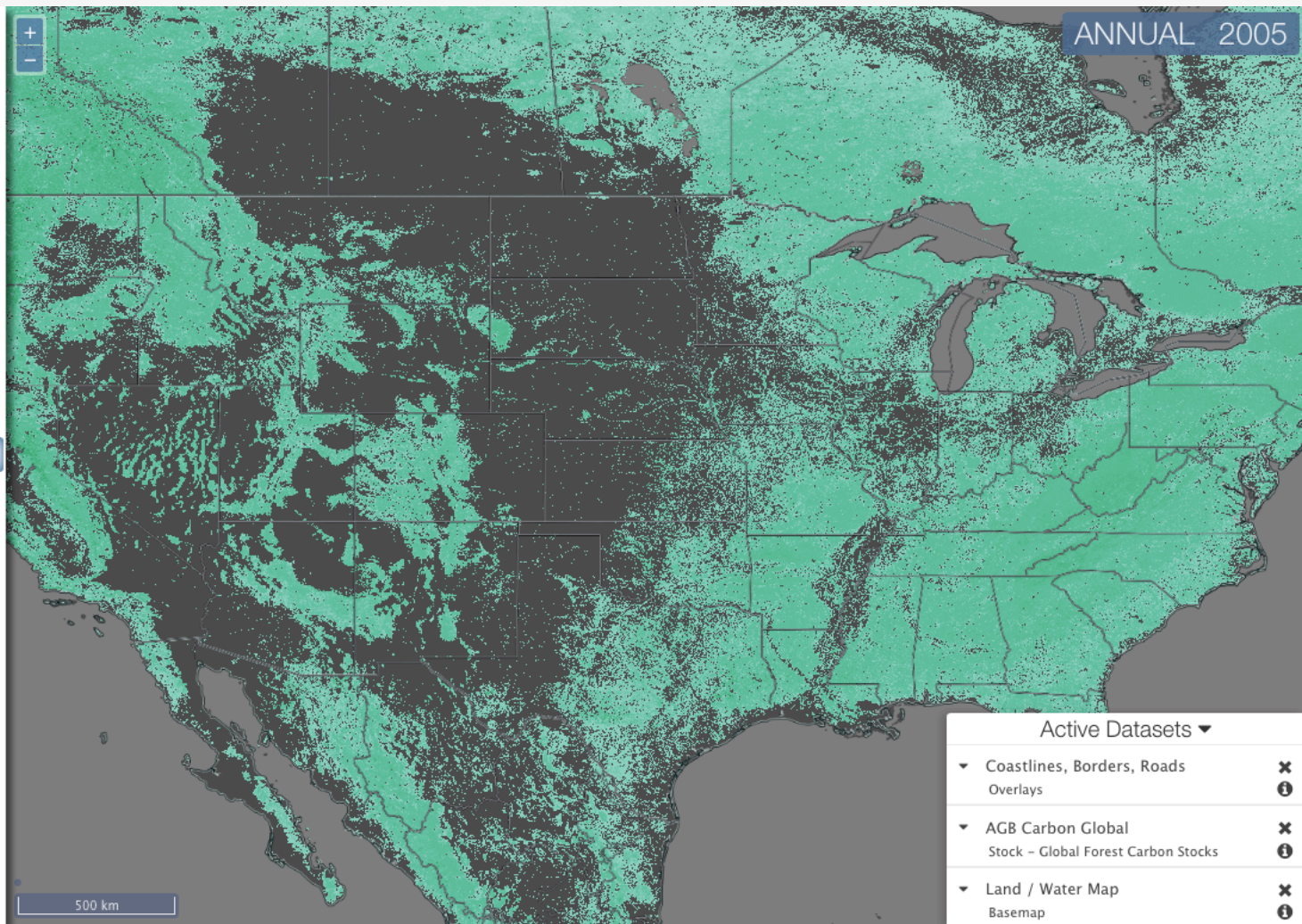
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Active Datasets ▼

- ▼ Coastlines, Borders, Roads Overlays ⓘ
- ▼ AGB Carbon Global Stock – Global Forest Carbon Stocks ⓘ
- ▼ Land / Water Map Basemap ⓘ

Map

Bar Chart

Time Series

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Carbon Mapper

Data Discovery

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Compare a dataset's regional sum to its uncertainty. ⓘ



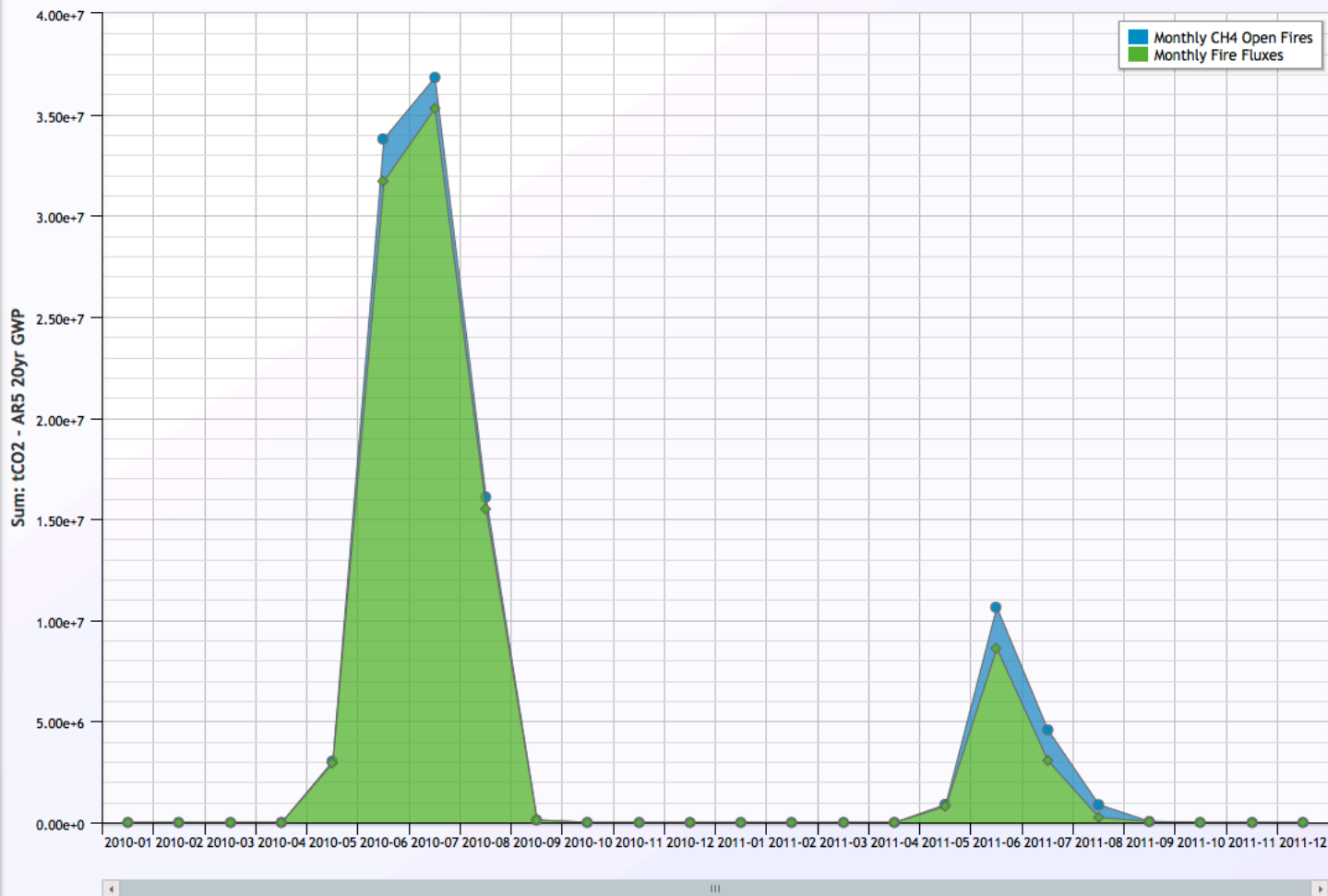
Map

Bar Chart

Time Series

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North American boreal





Carbon Mapper

Data Discovery

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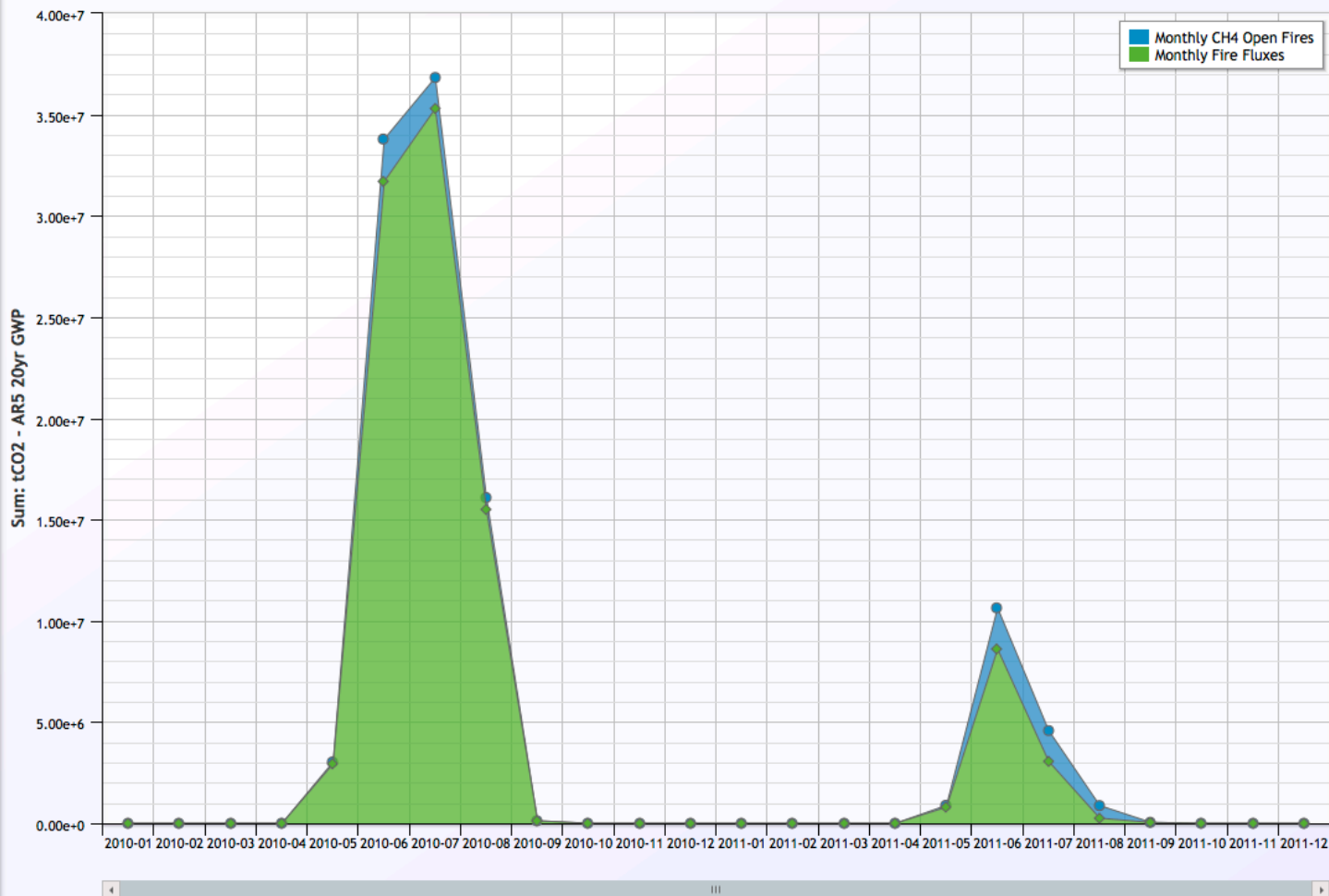
Map

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North American boreal





Carbon Mapper

Data Discovery

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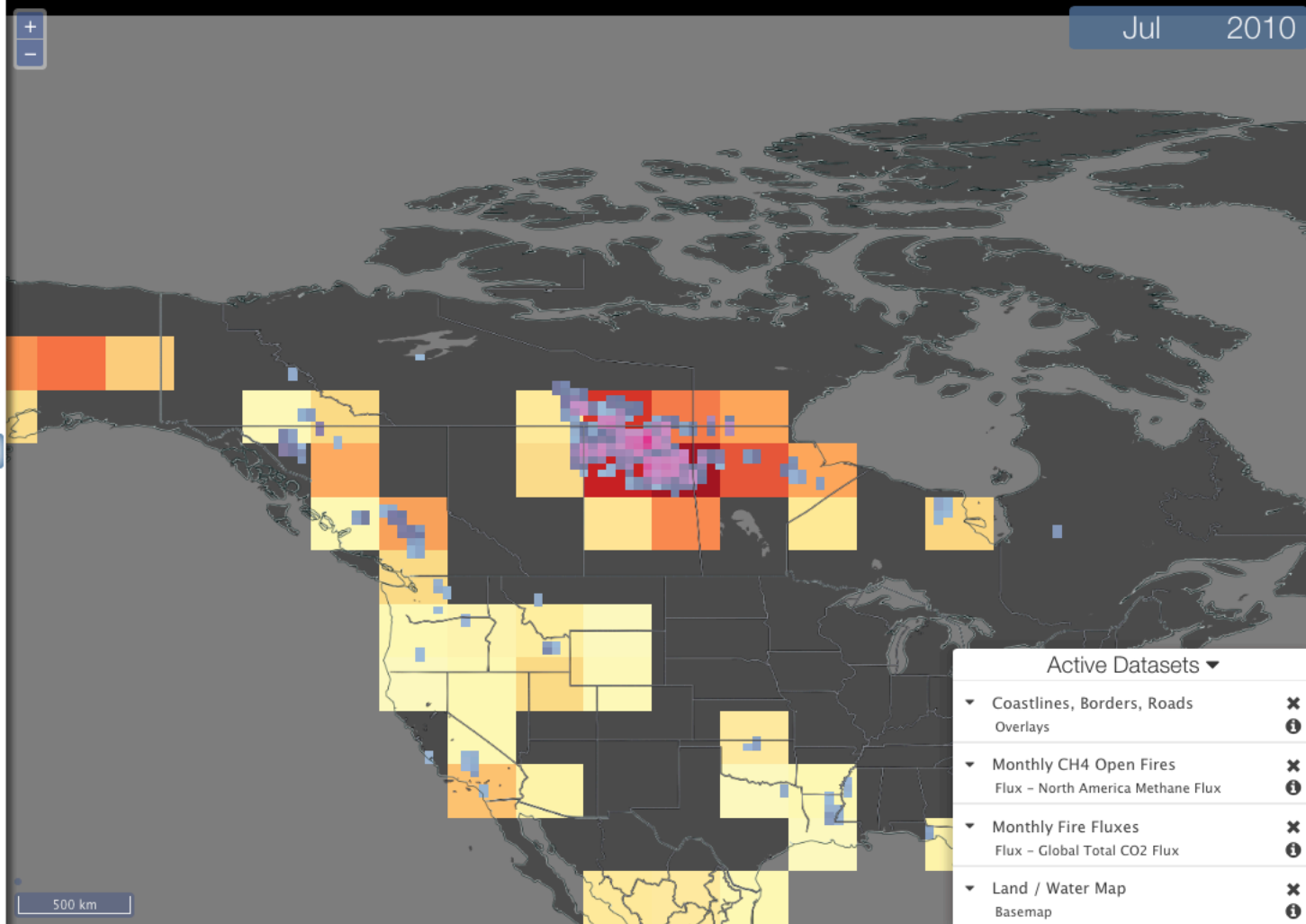
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Compare a dataset's regional sum to its uncertainty. ⓘ



Jul 2010

Active Datasets ▼

- ▼ Coastlines, Borders, Roads Overlays ⓘ
- ▼ Monthly CH₄ Open Fires Flux - North America Methane Flux ⓘ
- ▼ Monthly Fire Fluxes Flux - Global Total CO₂ Flux ⓘ
- ▼ Land / Water Map Basemap ⓘ

Map

Bar Chart

Time Series

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Data Discovery

North America Methane Flux

Version: carbon flux is there due to Forest

August 2015

Principal Investigator

Alex Turner and Dr. Daniel Jacob - Harvard University

URL

Not yet available

Summary

This dataset quantifies methane emission over North America. Satellite observations of methane columns from the Greenhouse Gases Observing Satellite (GOSAT) were used to constrain methane emissions with an inversion based on the GEOS-Chem chemical transport model. The data is up to 50 km x 50 km resolution and covers 2011.

Units

Kilograms per year (kg/yr)

Map

Bar Chart

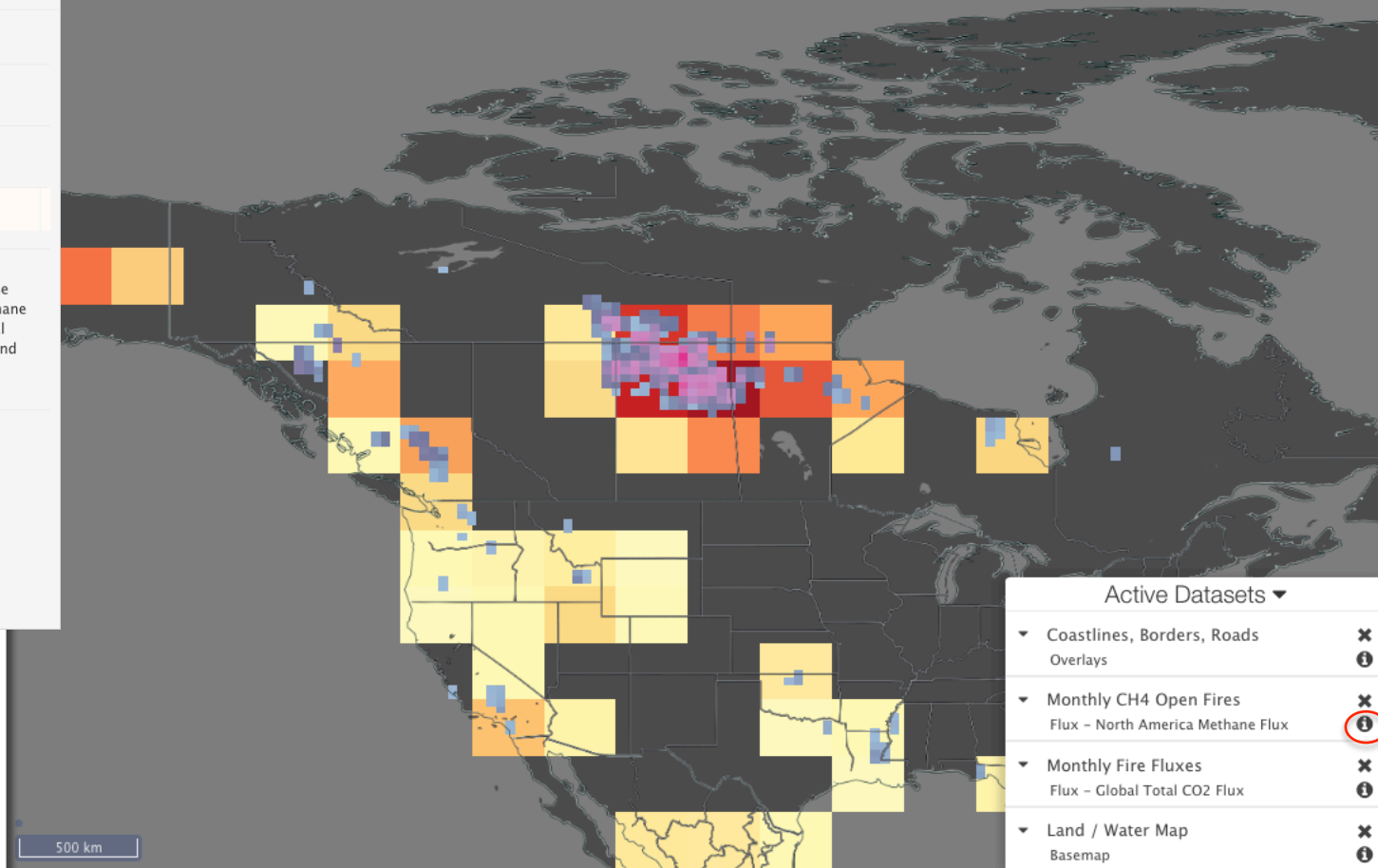
Time Series

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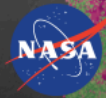
500 km



Active Datasets

- Coastlines, Borders, Roads Overlays
- Monthly CH4 Open Fires Flux - North America Methane Flux
- Monthly Fire Fluxes Flux - Global Total CO2 Flux
- Land / Water Map Basemap

One more example.....



Jet Propulsion Laboratory
California Institute of Technology

Carbon Mapper^{beta}

Start Exploring



Carbon Mapper

- Flux ⓘ
- Stock ⓘ
- Overlays ⓘ
- Basemap ⓘ



Map



Bar Chart



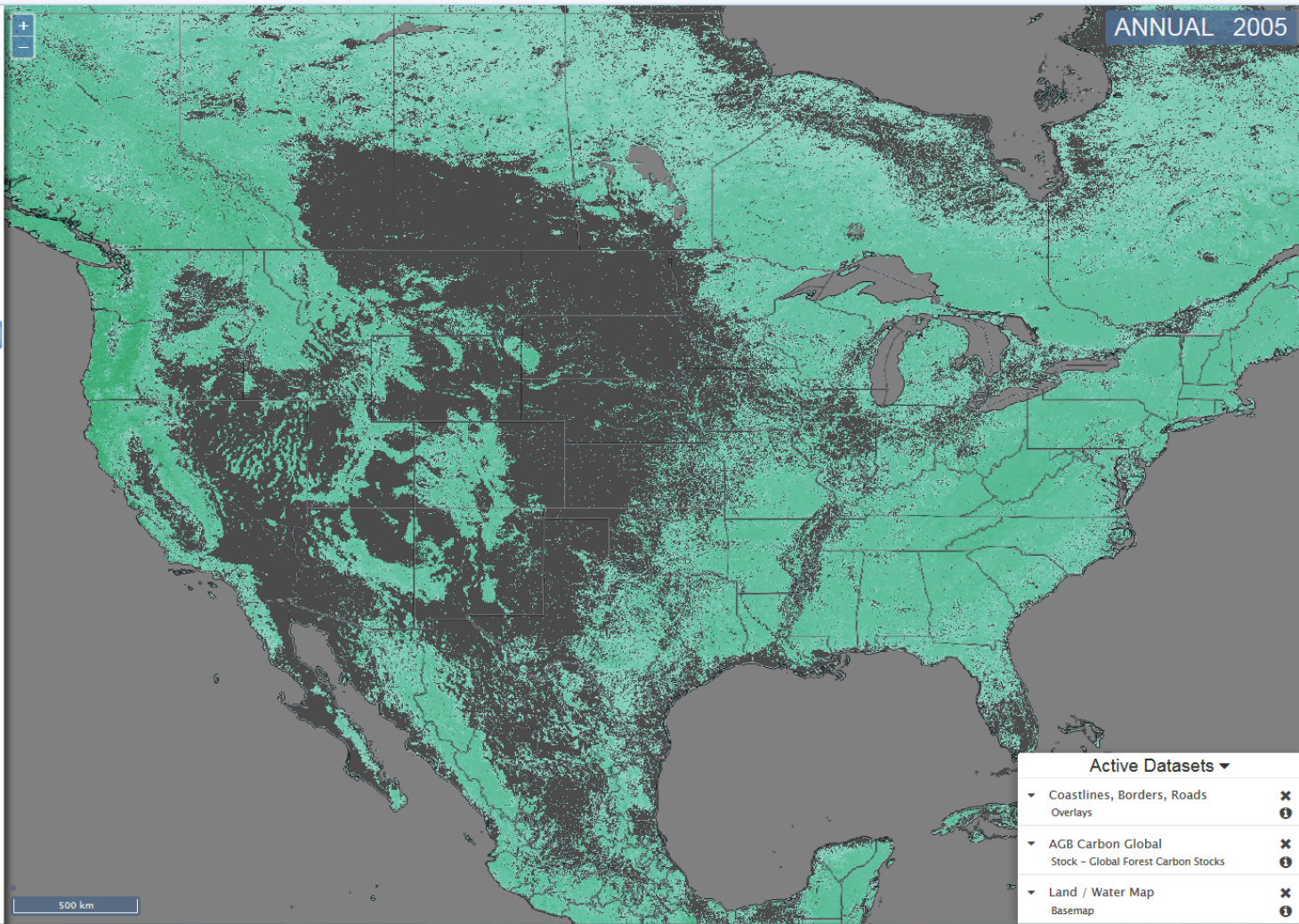
Time Series

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Active Datasets ▼

- Coastlines, Borders, Roads Overlays ☒ ⓘ
- AGB Carbon Global Stock - Global Forest Carbon Stocks ☒ ⓘ
- Land / Water Map Basemap ☒ ⓘ



Carbon Mapper

Flux

Global Cropland Carbon Flux

2005, 2006, 2007, 2008, 2009, 2010, 2011

Global Fossil Fuel CO₂ Flux

1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004,
2005, 2006, 2007, 2008, 2009, 2010

Global Total CO₂ Flux

2010, 2011

North America Methane Flux

2010, 2011

US Forest Carbon Flux

2005, 2006, 2007, 2008, 2009, 2010

US Fossil Fuel CO₂ Flux

2002

Stock

Overlays

Basemap



Map



Bar Chart



Time Series

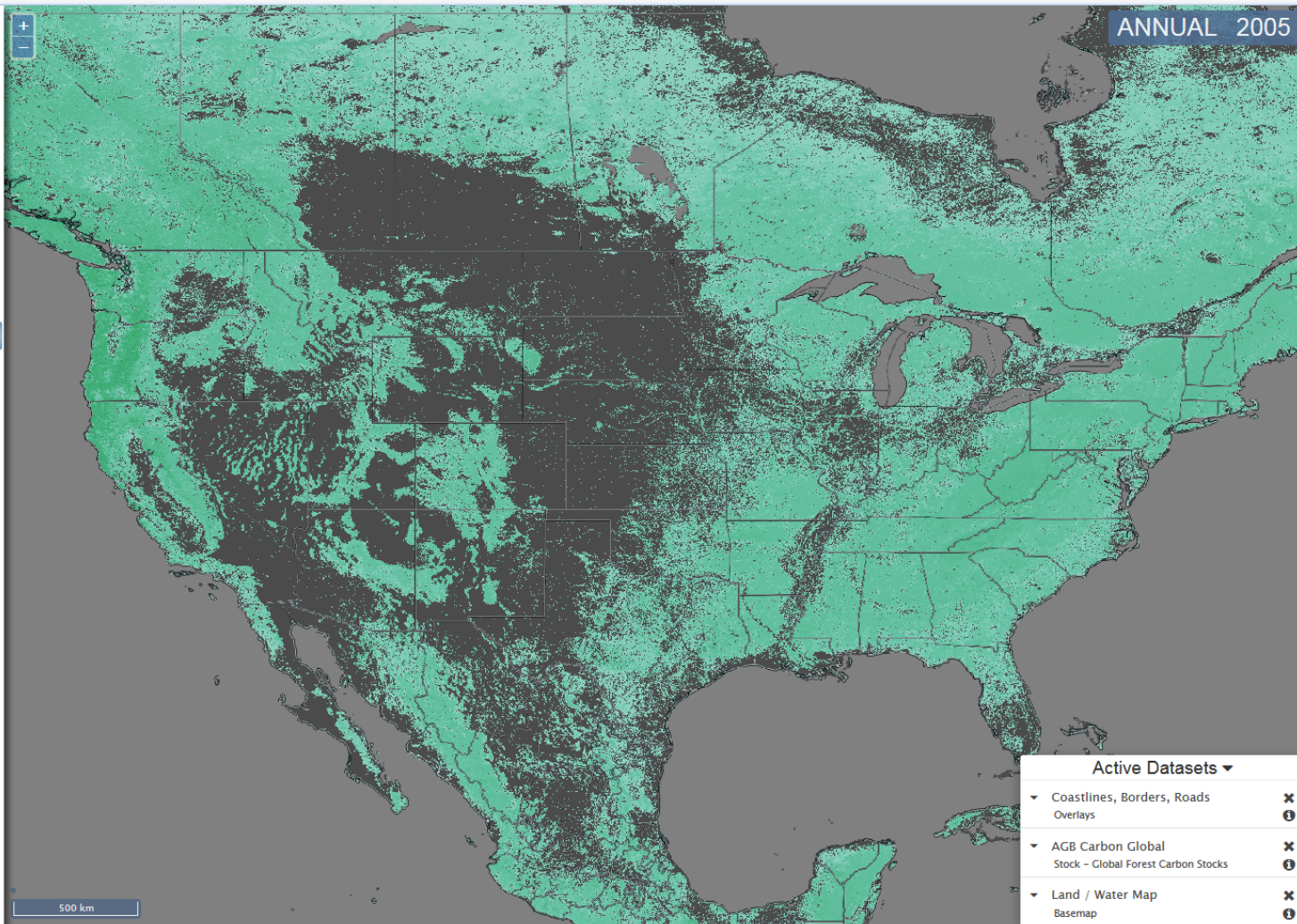
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+

-

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Active Datasets ▾

- ▾ Coastlines, Borders, Roads Overlays ☒ ⓘ
- ▾ AGB Carbon Global Stock - Global Forest Carbon Stocks ☒ ⓘ
- ▾ Land / Water Map Basemap ☒ ⓘ



Carbon Mapper

Flux

Global Cropland Carbon Flux

2005, 2006, 2007, 2008, 2009, 2010, 2011

Global Fossil Fuel CO₂ Flux

1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004,
2005, 2006, 2007, 2008, 2009, 2010

Global Total CO₂ Flux

2010, 2011

North America Methane Flux

2010, 2011

US Forest Carbon Flux

2005, 2006, 2007, 2008, 2009, 2010

US Fossil Fuel CO₂ Flux

2002

Stock

Overlays

Basemap



Map



Bar Chart



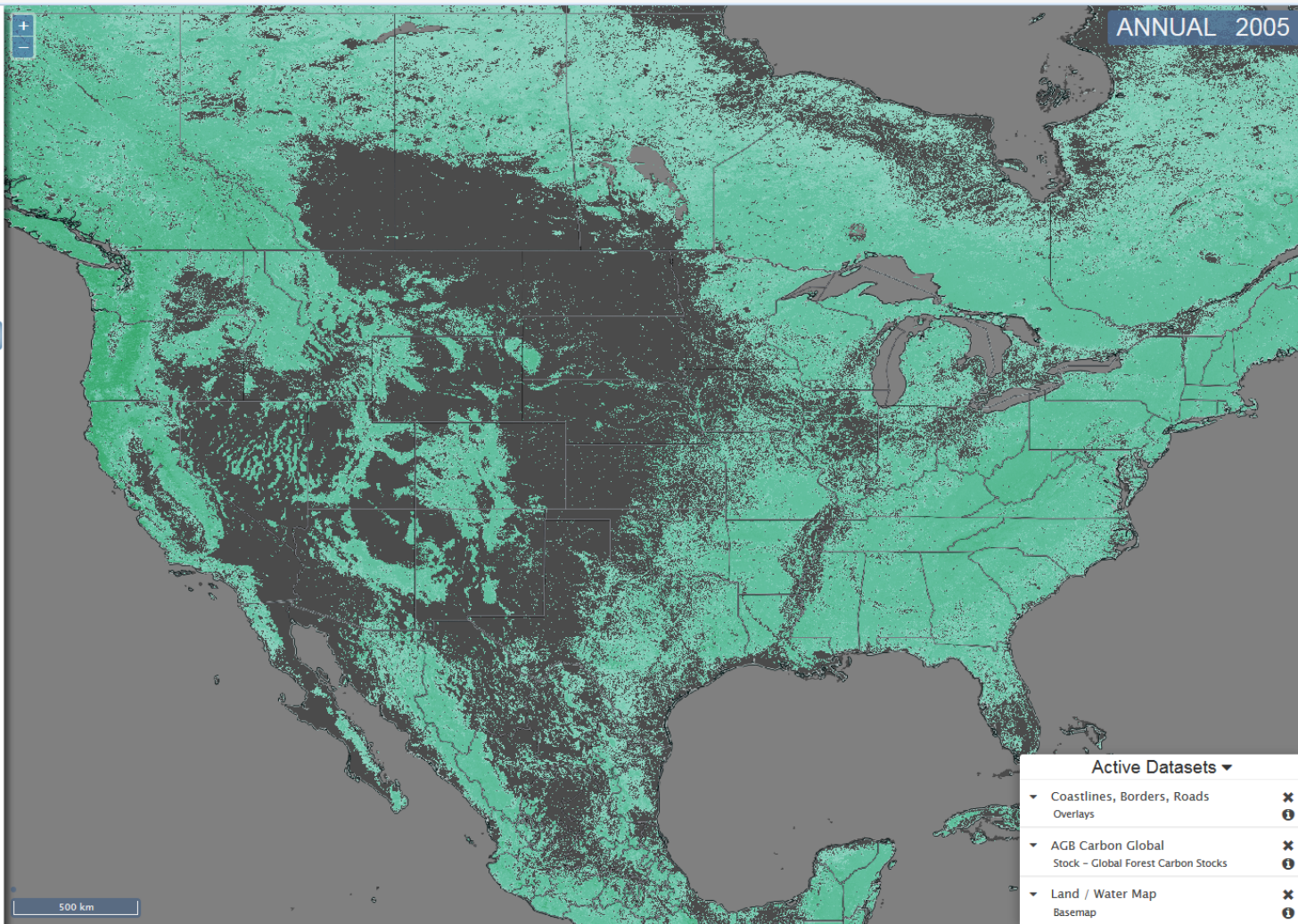
Time Series

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Active Datasets ▾

- Coastlines, Borders, Roads Overlays ☒ ⓘ
- AGB Carbon Global Stock - Global Forest Carbon Stocks ☒ ⓘ
- Land / Water Map Basemap ☒ ⓘ



Carbon Mapper

Flux



Global Cropland Carbon Flux



2005, 2006, 2007, 2008, 2009, 2010, 2011

Global Fossil Fuel CO2 Flux



1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004,
2005, 2006, 2007, 2008, 2009, 2010

FFDAS Total Uncertainty

FFDAS Totals

FFDAS Aviation (EDGAR)

FFDAS Electricity

FFDAS Other

FFDAS Shipping (EDGAR)

Toggle All



Global Total CO2 Flux



2010, 2011

North America Methane Flux



2010, 2011

US Forest Carbon Flux



2005, 2006, 2007, 2008, 2009, 2010

US Fossil Fuel CO2 Flux



2002



Stock



Overlays



Basemap



Map



Bar Chart



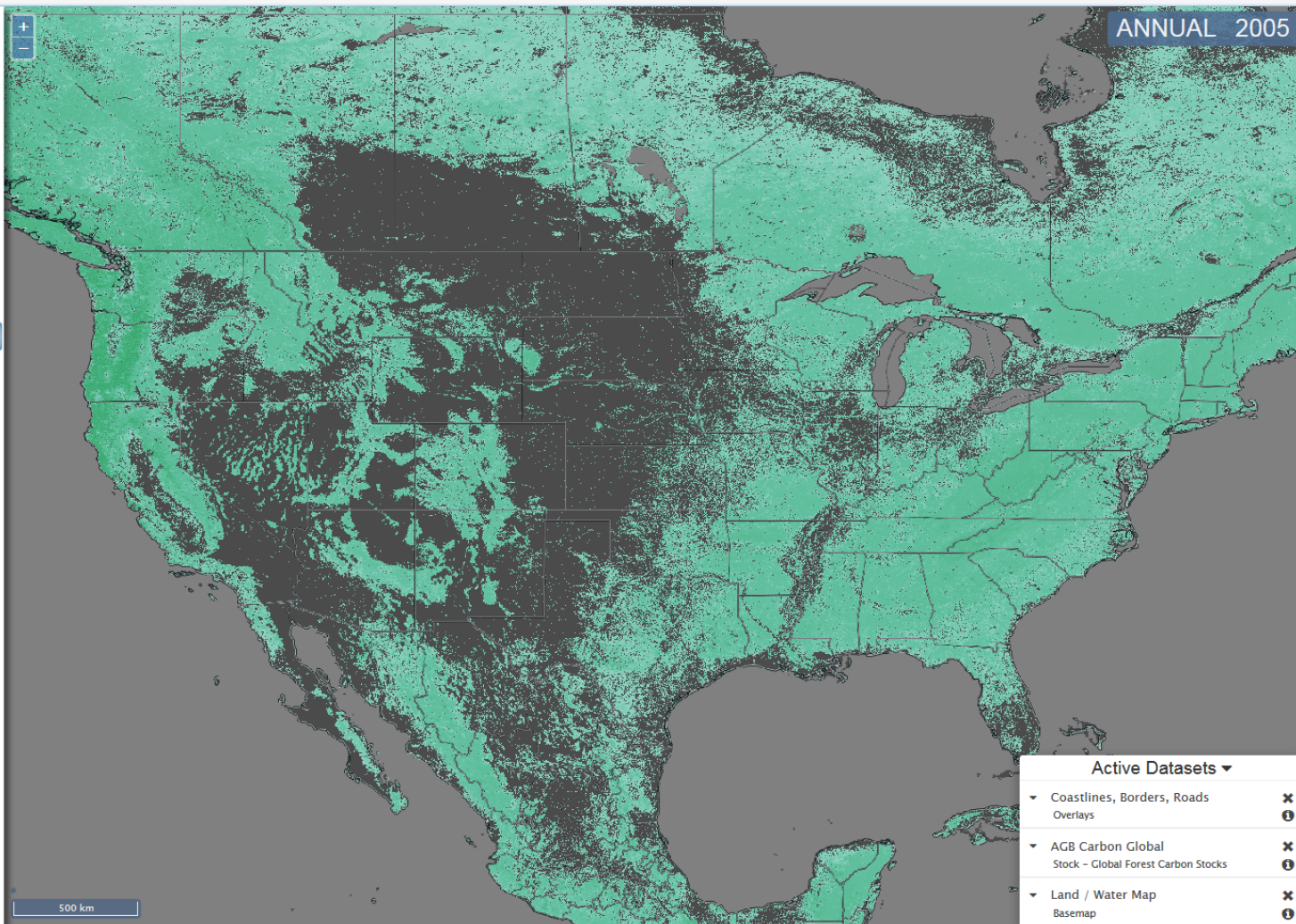
Time Series

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Active Datasets ▾

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- ▾ Land / Water Map Basemap  



Carbon Mapper

Flux



Global Cropland Carbon Flux



2005, 2006, 2007, 2008, 2009, 2010, 2011

Global Fossil Fuel CO₂ Flux



1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004,
2005, 2006, 2007, 2008, 2009, 2010

FFDAS Total Uncertainty

FFDAS Totals

FFDAS Aviation (EDGAR)

FFDAS Electricity

FFDAS Other

FFDAS Shipping (EDGAR)

Toggle All



Global Total CO₂ Flux



2010, 2011

North America Methane Flux



2010, 2011

US Forest Carbon Flux



2005, 2006, 2007, 2008, 2009, 2010

US Fossil Fuel CO₂ Flux



2002



Stock



Overlays



Basemap



Map



Bar Chart

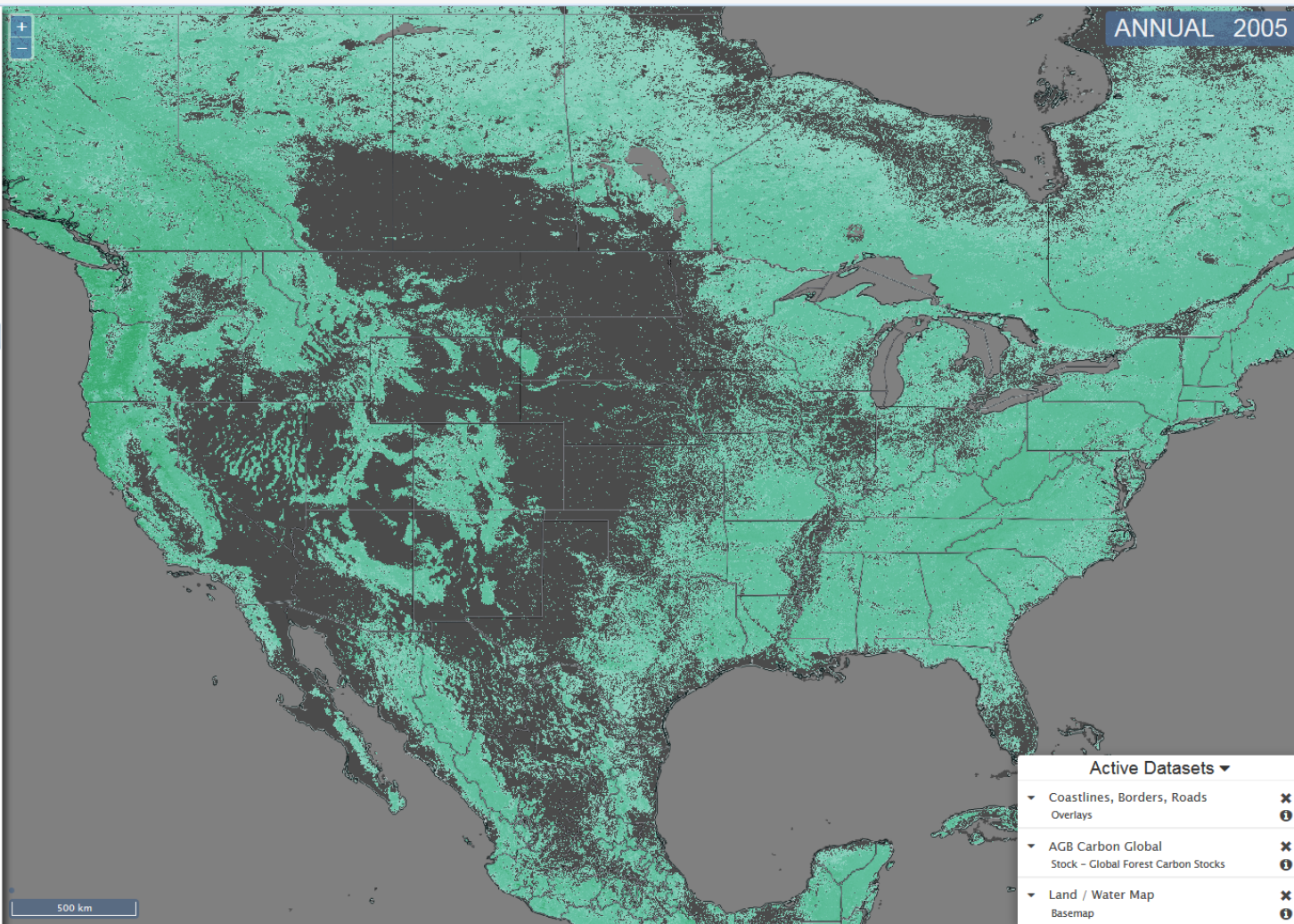


Time Series







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Active Datasets ▾

- Coastlines, Borders, Roads Overlays  
- AGB Carbon Global Stock - Global Forest Carbon Stocks  
- Land / Water Map Basemap  



Carbon Mapper

Flux

Global Cropland Carbon Flux

2005, 2006, 2007, 2008, 2009, 2010, 2011

Global Fossil Fuel CO2 Flux

1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004,
2005, 2006, 2007, 2008, 2009, 2010

FFDAS Total Uncertainty

FFDAS Totals

FFDAS Aviation (EDGAR)

FFDAS Electricity

FFDAS Other

FFDAS Shipping (EDGAR)

Toggle All

Global Total CO2 Flux

2010, 2011

North America Methane Flux

2010, 2011

US Forest Carbon Flux

2005, 2006, 2007, 2008, 2009, 2010

US Fossil Fuel CO2 Flux

2002

Stock

Overlays

Basemap

Map

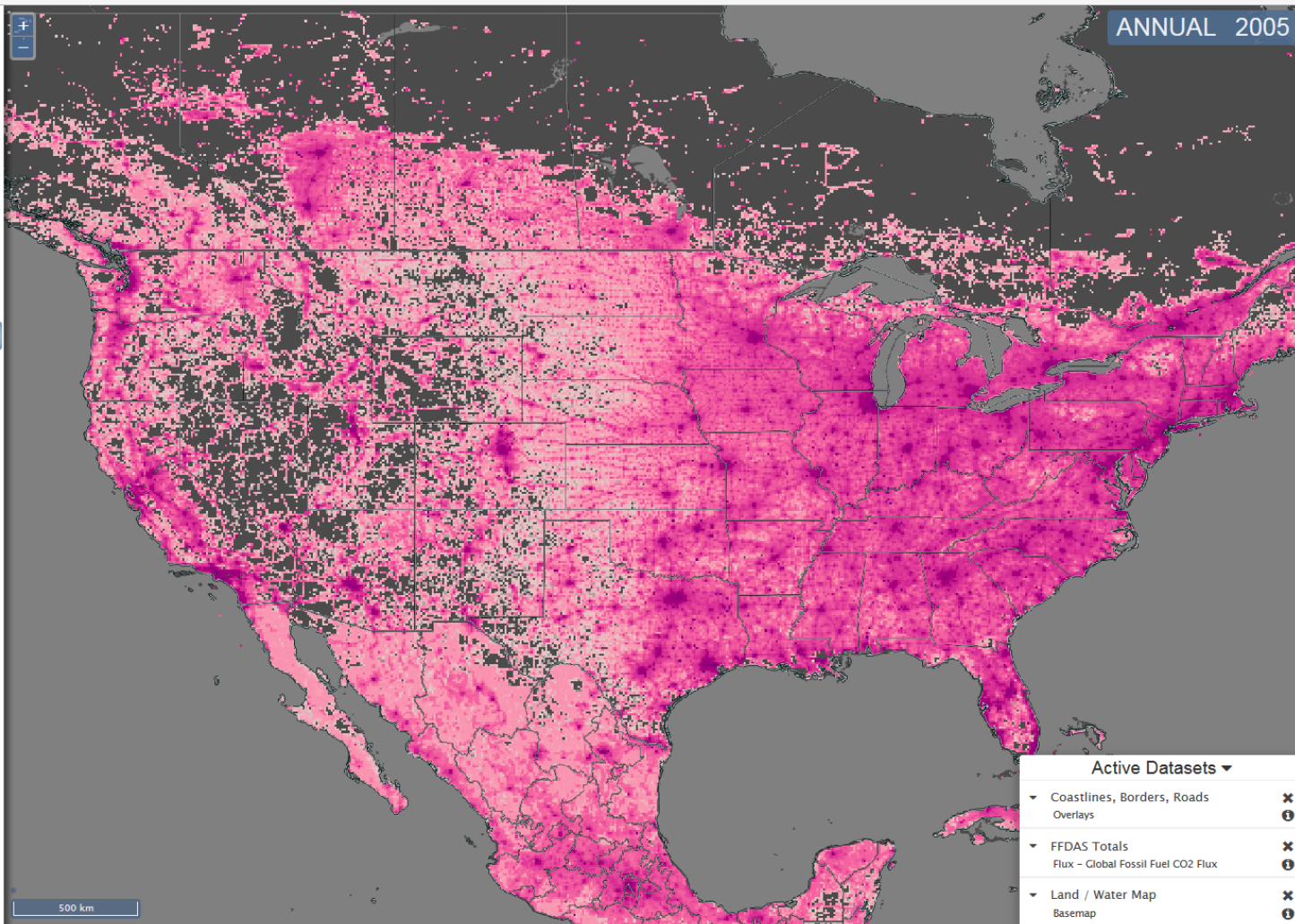
Bar Chart

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Active Datasets

Coastlines, Borders, Roads

Overlays

FFDAS Totals

Flux - Global Fossil Fuel CO2 Flux

Land / Water Map

Basemap



Flux



Global Cropland Carbon Flux



2005, 2006, 2007, 2008, 2009, 2010, 2011

Global Fossil Fuel CO2 Flux



1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004,
2005, 2006, 2007, 2008, 2009, 2010

FFDAS Total Uncertainty

FFDAS Totals

FFDAS Aviation (EDGAR)

FFDAS Electricity

FFDAS Other

FFDAS Shipping (EDGAR)

Toggle All

Global Total CO2 Flux



2010, 2011

North America Methane Flux



2010, 2011

US Forest Carbon Flux



2005, 2006, 2007, 2008, 2009, 2010

US Fossil Fuel CO2 Flux



2002

Stock



Overlays



Basemap



Map



Bar Chart



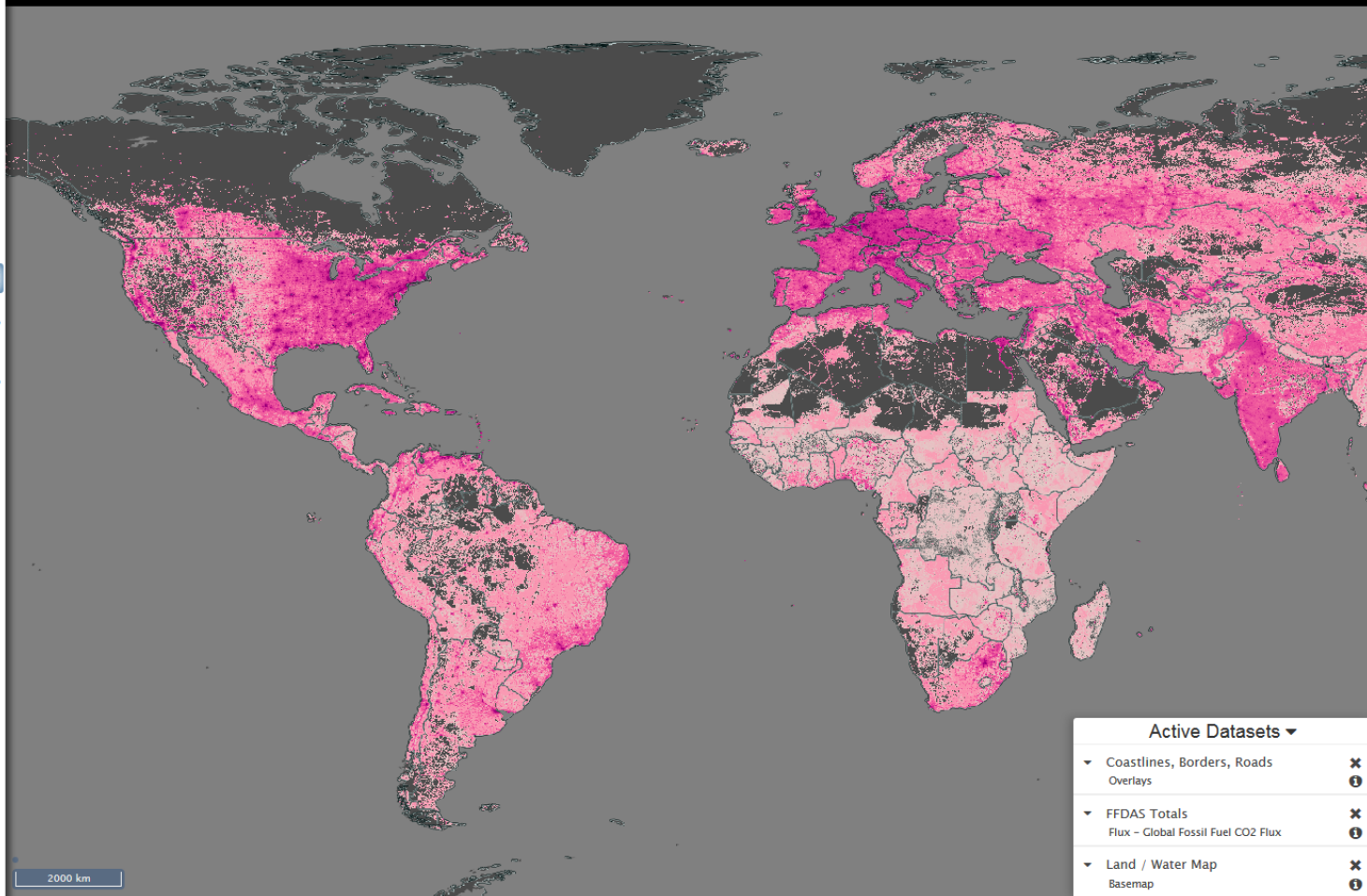
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2000 km



Active Datasets ▼

▼ Coastlines, Borders, Roads	✕
Overlays	1
▼ FFDAS Totals	✕
Flux - Global Fossil Fuel CO2 Flux	1
▼ Land / Water Map	✕
Basemap	1



Carbon Mapper

Flux

Global Cropland Carbon Flux

2005, 2006, 2007, 2008, 2009, 2010, 2011

Global Fossil Fuel CO2 Flux

1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004,
2005, 2006, 2007, 2008, 2009, 2010

FFDAS Total Uncertainty

FFDAS Totals

FFDAS Aviation (EDGAR)

FFDAS Electricity

FFDAS Other

FFDAS Shipping (EDGAR)

Toggle All

Global Total CO2 Flux

2010, 2011

North America Methane Flux

2010, 2011

US Forest Carbon Flux

2005, 2006, 2007, 2008, 2009, 2010

US Fossil Fuel CO2 Flux

2002

Stock

Overlays

Basemap

Map

Bar Chart

Time Series

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2007

1997

1998

1999

2000

2001

2002

2003

2004

2005

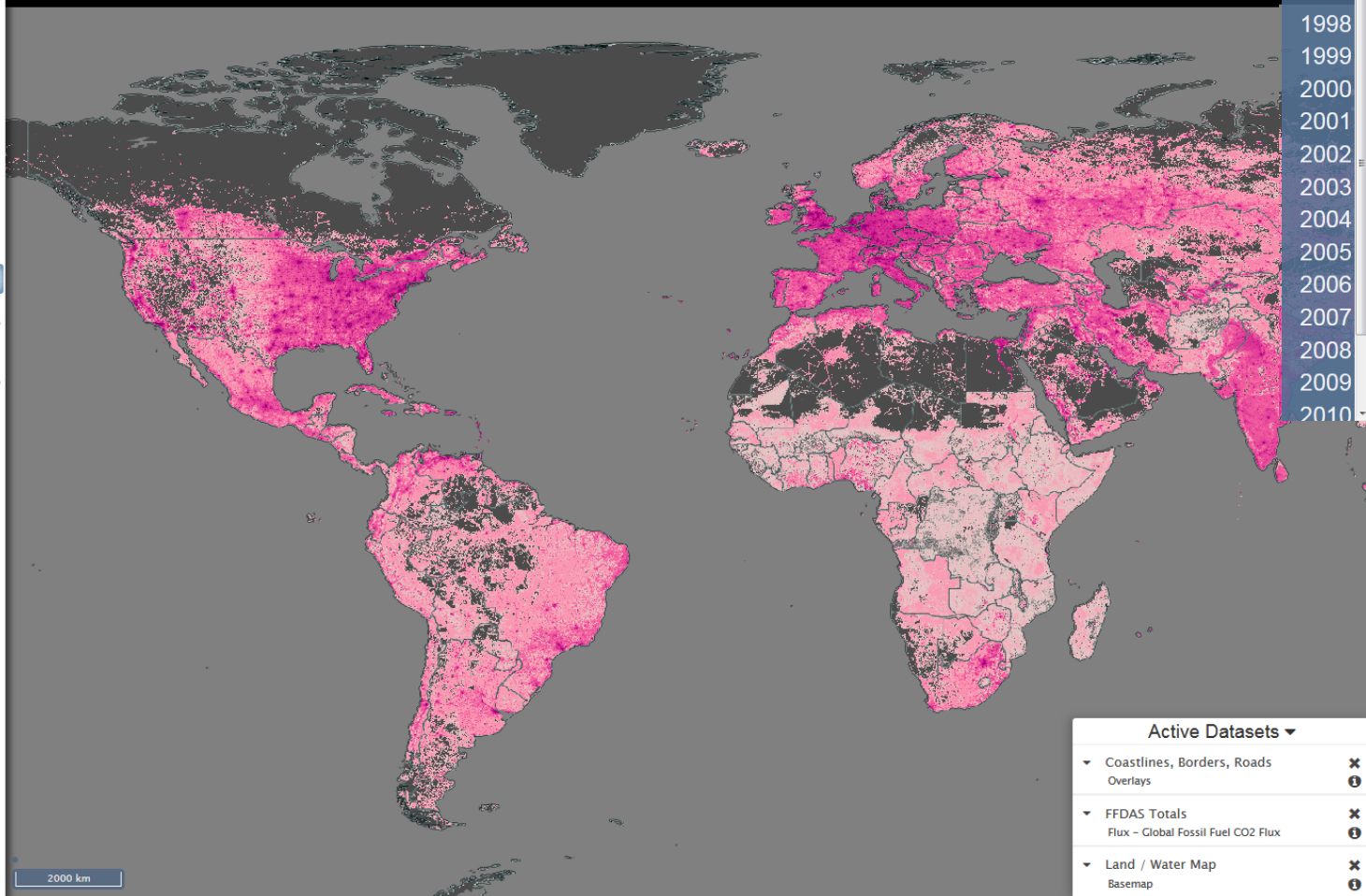
2006

2007

2008

2009

2010



Active Datasets ▼

Coastlines, Borders, Roads
Overlays

FFDAS Totals
Flux - Global Fossil Fuel CO2 Flux

Land / Water Map
Basemap



Data Scaling

Mass Eq. Unit

Unscaled

Compound Eq. Unit

Unscaled

☐ Standard Notation

Data Examination

Point Data

Box Histogram

Click on a pixel to retrieve data



Map



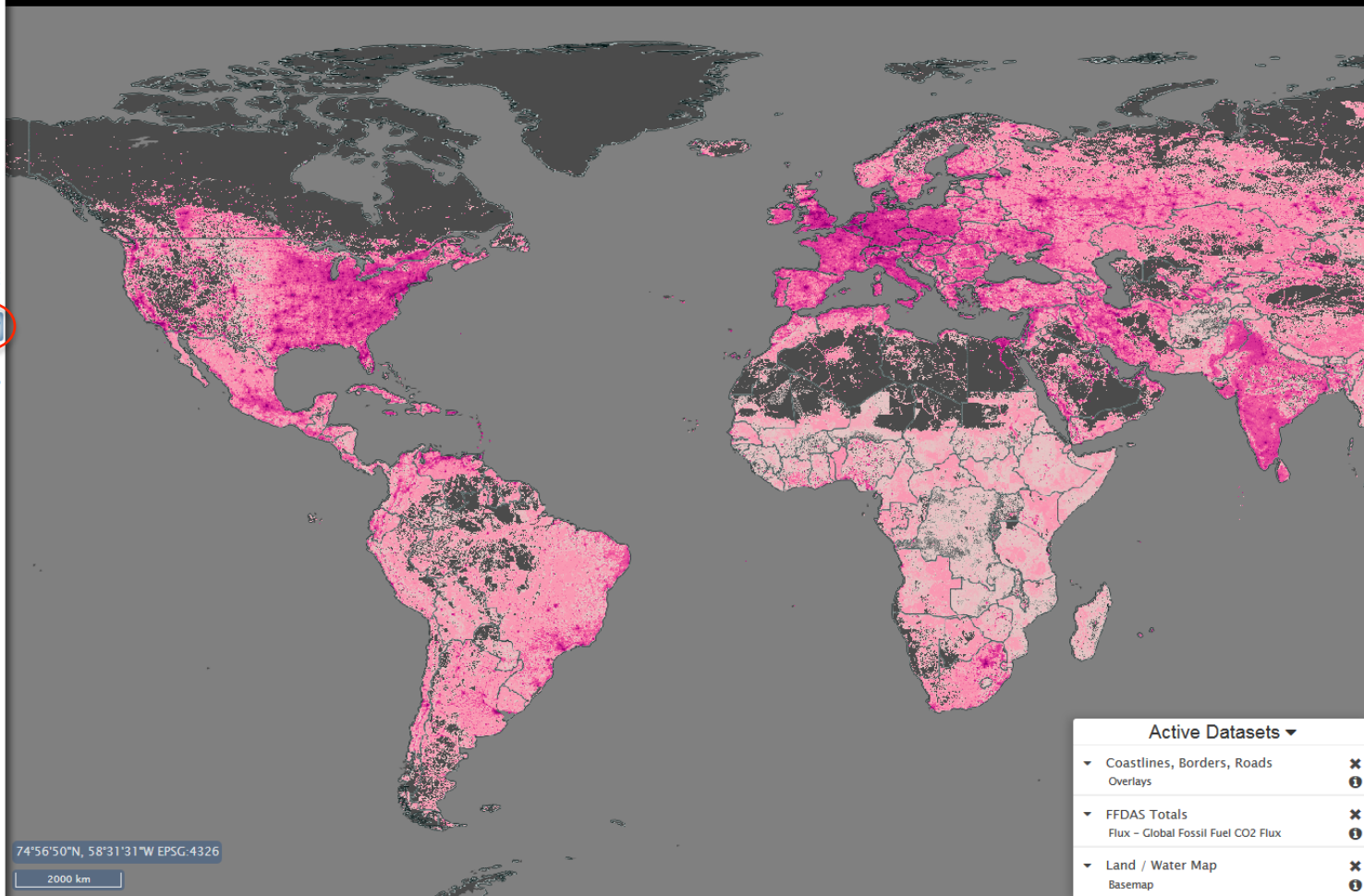
Bar Chart



Time Series

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Active Datasets ▾

▾ Coastlines, Borders, Roads	✕
Overlays	ⓘ
▾ FFDAS Totals	✕
Flux - Global Fossil Fuel CO2 Flux	ⓘ
▾ Land / Water Map	✕
Basemap	ⓘ



Data Scaling

Mass Eq. Unit

Unscaled

Compound Eq. Unit

Unscaled

☐ Standard Notation

Regional Selection

Region:

World

Country:

Export Table

Compare Subregions

Map

Bar Chart

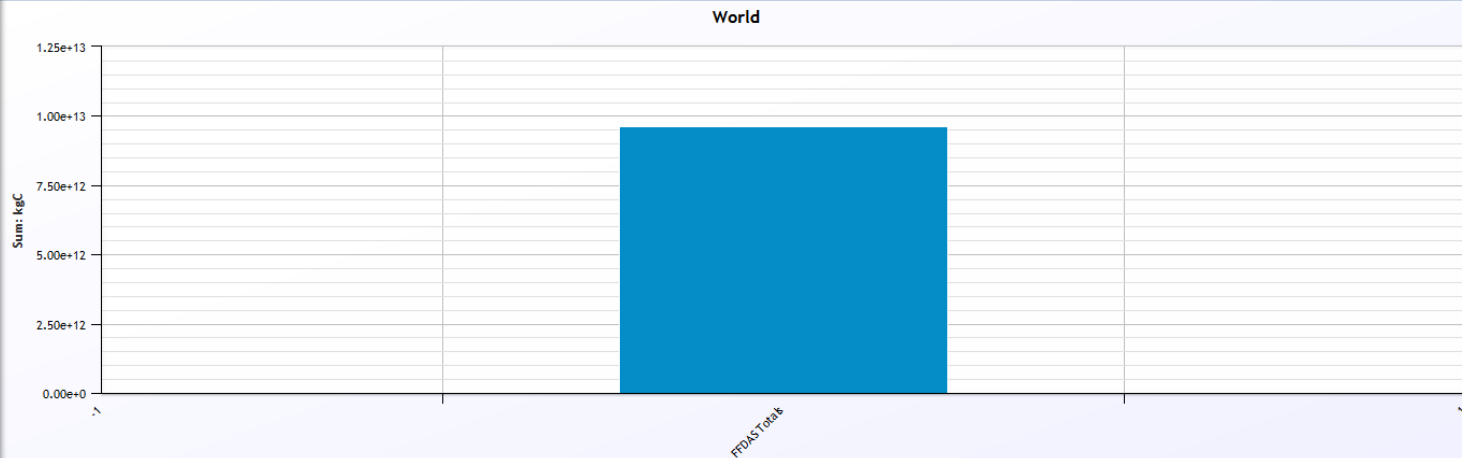
Time Series

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kgC

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	Sum	Mean	Max	Min	Std
FFDAS Totals	9.62e+12*	1.20e-2*	1.11e+2*	-2.63e+0*	3.92e-1*

* data entry was generated by Carbon Mapper Team





Carbon Mapper

Data Scaling

Mass Eq. Unit

Unscaled

Compound Eq. Unit

Unscaled

☐ Standard Notation

Regional Selection

Region:

World

Country:

Sort by Name

Sort by Total

Display by Value

Display by Percent

Show Table

Export Table

View Parent Region

Map

Bar Chart

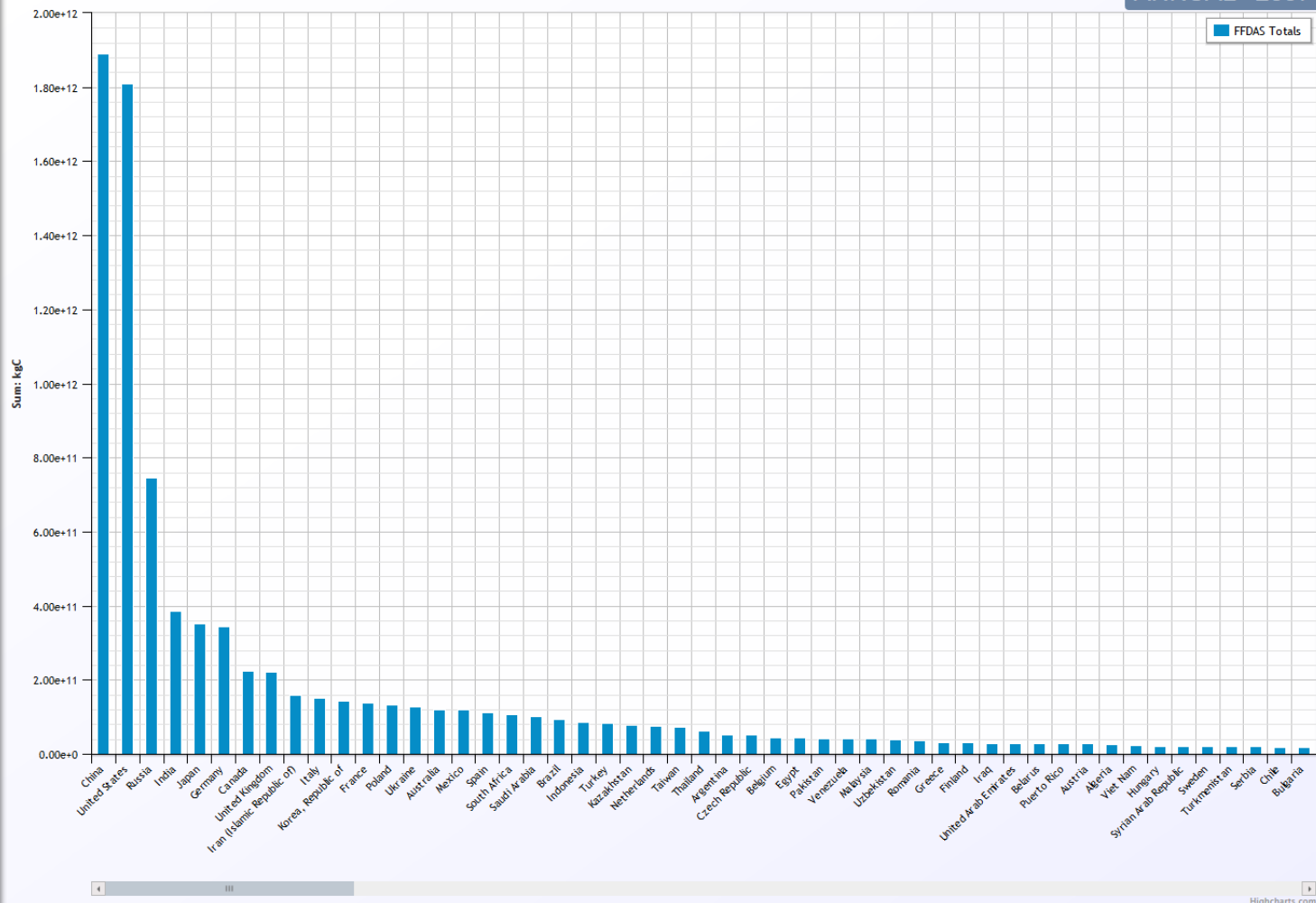
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Contacts

- ARSET Land Management & Wildfire Contacts
 - Cynthia Schmidt: Cynthia.L.Schmidt@nasa.gov
 - Amber McCullum: AmberJean.Mccullum@nasa.gov
 - Jenny Hewson (SilvaCarbon): Jhewson@conservation.org
- General ARSET Inquiries
 - Ana Prados: aprados@umbc.edu
- ARSET Website:
 - <http://arset.gsfc.nasa.gov>



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Space Administration



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Applied Remote Sensing Training

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<http://egsc.usgs.gov/silvacarbon/index.html>

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Thank You

Next Week:

*Carbon Estimation Techniques and
Methods*